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Farm Refrigerated Apple Storages

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The growing of apples is an important enterprise in New York State. For a number of years New York State has been second only to the State of Washington in the number of apples produced annually. The provision of adequate and satisfactory storage space is, therefore, a major problem.

In most of the apple sections of the State, the grower has the alternative of putting his fruit in commercial storage or providing storage facilities on the farm. The trend in recent years has been toward farm storages. Some of the reasons given are the long haul to the commercial storage, the congestion at the loading dock during the harvest season with the result that many apples sit in the hot sun for long periods, few or no apples at the farm for retail trade, lack of control over marketing, and competition for storage space.

On the other hand, some problems should be considered before the decision is made to build a farm storage. In the first place, storage facilities represent a sizable capital investment. Moreover, the grower is solely responsible for the operation and maintenance of the storage. He is also faced with the situation of handling his own marketing problems.

A wise decision can only be based on careful consideration of these and other problems peculiar to specific areas. The grower who is contemplating his own storage should first make an analysis of the commercial storage facilities available in his area. Such an analysis should include availability of storage space, storage charges, and handling and marketing operations. He should then carefully analyze his market demands to determine whether they might better be served by the commercial storage or by his own storage. Then he should have prepared detailed plans and estimates of cost for the construction of a storage to meet his needs. The results of such analysis should furnish the necessary information for making a sound and wise decision.

Types of storages

The three major types of farm storages are (1) the common, (also called *air-cooled* or *ventilated* storage), (2) the refrigerated, and (3) the controlled atmosphere. The common storage depends upon ventila-

tion for the cooling of apples. This is the greatest limitation of this type of storage. During the apple harvest season in the State, often there are warm days and warm nights. With outside air used for cooling, the storage cannot be brought to the desired temperature to hold apples until later in the season. Hence the storage period is short. Common storage is, however, the cheapest to build. For those growers who want to hold for a short period only, the common storage is the logical solution. Another possibility for keeping down the investment is a combination of common and refrigerated storage. The apples that are to be marketed earliest can be stored in the common storage, and those that are to be held longer can be stored in the refrigerated storage. Still another possibility is to construct a building for refrigerated storage but to operate it as common storage for the first few years. Later it can be converted to refrigerated storage. This plan spreads the investment costs over a longer period and, if the storage is built properly in the first place, the conversion can be made quite easily. Complete details on the construction and operation of common storages can be found in Cornell Extension Bulletin 453, *The Air Cooled, or Common, Apple Storage and Its Management*.

In the refrigerated storage, the temperature is maintained by the use of refrigerating equipment. Although the investment is higher than for a common storage, the apples can be cooled quickly to the desired temperature and held over a considerably longer period. Thus the apples can be marketed at a period of relative scarcity when they will usually command a higher price than if sold at harvest time.

The controlled-atmosphere storage is in reality a refrigerated storage, but with the additional control of the oxygen and the carbon dioxide content of the air to further lengthen the storage period. Detailed information on the operation and management of controlled-atmosphere storages can be found in Cornell Extension Bulletin 759, *Controlled-Atmosphere Storage of Apples*.

This bulletin is concerned only with the construction and management of refrigerated storage, and some of the construction details peculiar to controlled atmosphere storages.

Requirements of Apple Storages

THE purpose of any apple storage is to keep the stored fruit in a marketable condition over a period of time. To accomplish this purpose, the apples should be placed in storage as soon as possible after they are picked, and they should be cooled to the holding temperature as quickly as possible after they are loaded into storage.

Rapid "cool down"

The apple is a living organism and will finally die from old age if not from disease after it has been separated from the tree. The rate of respiration, which varies according to the temperature, can be controlled to some extent by the storage temperature.

The respiration rate of apples is approximately doubled or trebled for every 18° F. rise in temperature. In other words, an apple ripens about two or three times as fast at 50° F. as it does at 32° F. and about two or three times as fast at 68° F. as at 50° F. For example, assume that apples are brought into the storage at 68° F. and are cooled to the "holding" temperature of 32° F. in one week. Assume also that the apples stay at 68° F. for four days, then the temperature is dropped to 50° F., held there for three days, and then dropped to 32° F. The first four days at 68° F. are comparable to sixteen days at holding temperature (32° F.), and the three days at 50° F. are comparable to six days at holding temperature. In other words, the storage life of apples cooled under these conditions is shortened by twenty-two days. In actual practice, the conditions would not be so extreme because the "cool down" is gradual and starts immediately, and it is not conceivable that the apples would remain at 68° F. for four days. On the other hand, apples are often brought into storage at temperatures exceeding 68° F. The importance of cooling the apples to holding temperature as rapidly as possible cannot be over emphasized. For this reason, refrigerating equipment is designed to cool the fruit in 24 hours. In actual practice the apples are not brought to storage temperature in this time, but actual practice has shown that this figure must be used to insure enough cooling capacity.

Holding temperatures

From the example given it would seem that the lower the temperature, the longer the life of the apples in storage. There are, however, limitations to this theory. Some varieties of apples are susceptible to low-temperature troubles, such as soft scald, brown core, and soggy breakdown. Apples contain about 85 per cent water which freezes at 32° F. Dissolved sugars and other materials in the juice depress the freezing point to about 27° or 28° F. depending on the variety.

If the temperature were held at just about freezing, a slight fluctuation could drop the temperature below the freezing point and injure the fruit. Consequently, in New York State the most commonly used and recommended holding temperature for apples is 32° F.

Controlled-atmosphere storages may be run at a higher temperature during the holding period for certain varieties, such as McIntosh; but

when the storage is opened at market time, the temperature is usually brought down to 32° F. Consequently, design is based on this temperature.

Relative humidity

Apples in a dry atmosphere lose moisture and shrivel. Ideally, to prevent shriveling, the relative humidity of the storage atmosphere should approach 100 per cent. Such high humidities are, however, conducive to the growth of molds. Furthermore, this high humidity is practically impossible to maintain. Consequently, 90 per cent relative humidity is recommended.

Air distribution

By air distribution is meant the movement of air *within* the storage itself. Good air distribution is essential to rapid cooling of the fruit and to the maintenance of a uniform temperature distribution throughout the storage. It must be remembered that it is useless to cool the surface layers of fruit unless the fruit in the centers of the stacks can also be cooled. Good air distribution, especially through the stacks, removes the warm air in the center and replaces it with cool air, thus cooling the en-

Figure 1. A two-story refrigerated apple storage built into a bank. View from the lower ground level

tire mass of fruit. Even at holding temperature a good distribution of cool air insures a uniform temperature throughout the storage and inside the stacks of fruit.

Proper air distribution also prevents high concentrations of scald gases and ripening gases within the stacks. These gases reduce the quality of the fruit and shorten the storage life of the apple.

Ventilation

The question is often raised as to the benefits of ventilation in a refrigerated storage to reduce the cost of operation during the colder months and to reduce scald. The length of time that the outside temperature is below storage temperature is so short that the resulting saving in operating costs is negligible. Moreover, ventilation tends to reduce the humidity of the storage. To date there is no evidence of ventilation after December 1 having any appreciable effect on reducing scald. Consequently, ventilation is not recommended for refrigerated storages. It could not be used in controlled-atmosphere storages because ventilation would make it impossible to maintain the desired oxygen and carbon dioxide content of the air.

Construction

Location

The apple storage is an integral part of the apple business. It should be an asset rather than a liability. Accessibility and convenience are of prime importance in the location of the structure itself.

At loading time, the fruit is brought from the orchard directly to the storage building. A long haul to an out-of-the-way spot is a time-consuming operation. On the other hand, if the owner markets his own fruit, convenience to the market outlet is a consideration. Nearness of the market to the farmstead and access to a hard road that is cleared in the winter are important. When the apples are sold to a wholesaler, the buyer naturally considers whether or not the storage is easily accessible for transportation of the fruit to market.

The ground on which the storage is built should be carefully considered. A two-story building built into a bank has much to recommend it. Apples can be moved in and out of the first floor from the lower ground level and to and from the second story at the higher ground level. From a practical standpoint, it is cheaper to move the fruit horizontally than up and down. An excellent example of a two-story bank storage is shown in figures 1 and 2.

When the ground is level, the question often arises whether to build the storage aboveground or to dig a basement. Some growers believe

Figure 2. A view of the storage shown in figure 1 from the upper ground level

that less insulation is required if the walls are below ground because of a uniform ground temperature. It should be remembered, however, that frost penetrates as much as 4 feet below ground, so it is reasonable to expect the same of summer heat. Hence, it does not seem advisable to reduce the amount of insulation below ground. The cost of excavation for a basement is another consideration. Also, special provisions must be made for moving the fruit up and down when loading and unloading.

If a two-story structure is built on level ground, handling operations to the second story of an above-ground storage are about the same as the handling operations to the basement of a below-ground storage, and comparative construction costs are of greater importance.

Any chosen site should have adequate drainage. Water standing around the foundation causes rapid deterioration and increases the chances of water leakage into the storage. Methods of drainage are discussed fully in Cornell Extension Bulletin 741, *Roofs and Foundations.*

Size and shape

From the standpoint of heat leakage, the ideal shape for a refrigerated storage is a cube because there is less exposed surface area per cubic foot of capacity than in any other rectangular shape. From a practical standpoint, this is not possible. There are limits to the height to which apples can be conveniently stacked. The experience of storage operators indicates that a maximum stack height of 12 feet in the clear is the most

practical for hand stacking. With an overhead-clearance allowance for air distribution, the ceiling height for this stack would be 14 feet.

When the apples are palletized and handled by fork-lift trucks, stack heights up to 20 feet can be handled conveniently (figure 3). This requires a ceiling height of 22 feet.

Figure 3. Handling palletized apples in a storage with a fork-lift truck

Very wide buildings require columns inside the storage for roof support; otherwise elaborate and expensive trusses must be installed. Self-supporting roofs can be built on narrow buildings with relatively simple trusses or steel girders. For this reason, widths most commonly used range from 30 to 40 feet.

When calculating the size of a storage, it is customary to allow about 2.5 cubic feet of storage space for each bushel of fruit stored. This figure allows for aisle space, overhead clearance, and space between containers. In palletized storage, this figure should be increased by about 20 per cent to about 3 cubic feet per bushel. The additional allowance is for

***Table 1.* Possible dimensions for storage buildings of different capacities**

Approximate capacity		Ceiling height	Floor area per floor		Inside dimensions	
			One-story	Two-story	One-story	Two-story
Bushels	*Cubic feet*	*Feet*	*Square feet*	*Square feet*	*Feet*	*Feet*
5,000	12,500	14	893	....	30 x 30	......
7,500	18,750	14	1,340	....	30 x 45 34 x 40	....
10,000	25,000	14	1,786	893	30 x 60 40 x 45	...... 30 x 30
15,000	37,500	14	2,680	1,340	40 x 67	30 x 45 34 x 40
20,000	50,000	14	3,572	1,786	40 x 90	30 x 60 40 x 45

the space taken by pallets and the additional aisle space required to maneuver the fork truck.

Dimensions of different capacity storages based on a 14-foot ceiling height are given in table 1. These inside dimensions would be modified somewhat for other ceiling heights.

Insulation and insulating materials

Insulation is a material used in wall, ceiling, floor, or roof construction primarily to reduce the rate of heat transfer through the structure. The ability of a material to conduct heat through a unit thickness is called its *thermal conductivity;* the resistance of the material of unit thickness to the flow of heat is its *thermal resistivity.* The conductivity of a material is the reciprocal of its resistivity; that is, conductivity $= \dfrac{1}{\text{resistivity}}$.

The flow of heat through any structure can be likened to the flow of water through a pipe. The quantity of water that flows out of a pipe depends upon the pressure behind it, the resistance of the pipe, and the size of the pipe. The pressure is the force that moves the water; the resistance of the pipe tends to retard the flow and must be overcome by the pressure; and the size or area of the pipe determines how large a quantity can move through the pipe at one time. In heat flow through a wall, the difference in temperature from one side to the other is the force that causes the heat to flow. The thermal resistivity of the insulation tends to retard the flow of heat, and the area of wall involved determines the total quantity of heat flowing through the wall.

The temperature inside the refrigerated storage is much lower than the outdoor temperature during loading time. Consequently, the temperature difference, or the force tending to move the heat, is relatively high. To keep the heat flow into the storage at a minimum, an insulation that has a high resistance to the flow of heat is used.

Many types of insulation materials are available. Some of them are commercial and some are native, such as sawdust, shavings, and the like. To be of greatest value, the materials should have good insulating qualities, must be dry, and should be economical, relatively easy to put in place, odor free, and vermin proof.

Based on physical characteristics, insulating materials may be divided into four classes: (1) reflective, (2) rigid, (3) flexible, and (4) loose fill.

Reflective insulation derives its name from the fact that it has a bright shiny surface that reflects radiant heat much as a bright shiny object reflects the sunlight. Such insulation is typified by aluminum sheets or aluminum foil. This type of insulation loses its effectiveness when placed in contact with the building or other materials. For best results, a $\frac{3}{4}$-inch

air space between this insulation and any other material, and between the layers of this type of insulation, is recommended. When reflective insulation is placed between studs, precautions must be taken to prevent air movement by convection between the layers. Air next to the layer on the warm side rises and that on the cold side falls thus setting up convection currents that take up heat on the warm side and give it up at the cold. This increases the rate of heat transfer and reduces the effectiveness of the insulation. To prevent this air movement, horizontal wood strips should be placed about 30 inches apart between the layers.

Rigid insulation is made up of rigid boards of insulating material that can be laid up against the sheathing. Rigid insulation has considerable structural strength, and some types are used as sheathing.

Flexible insulation is made up of blankets or bats of insulating material that can be laid up against sheathing between studs and joists. These blankets have no structural strength and depend upon the structure to support them.

Loose-fill insulation consists of loose or granular insulating material. This type of insulation has no structural strength and must be poured into a rigid container as the space between the inside and outside sheathing. Included in this class are native materials, such as sawdust, shavings, and buckwheat hulls.

To determine the particular insulation to use, the grower should choose the one that gives him the desired insulating value for the least expenditure for material and construction.

Materials of construction other than insulation also offer resistance to the flow of heat. Although this resistance is small compared with that for insulation, it still should be included in determining the overall rate of heat flow.

There is additional resistance to heat flow from a solid surface to air in contact with it and from air to a solid surface. In storage-wall construction two of these surfaces need to be considered, one inside and one outside. The outside surface offers less resistance because the sweeping action of wind tends to increase the rate of heat transfer.

In some types of wall construction, air spaces are left. These air spaces resist the flow of heat mainly because of the resistance of the bounding surfaces. Under most normal conditions, the resistance of an air space increases with the thickness of the space up to $\frac{3}{4}$ inch. Beyond that, the increase is slight and, for practical considerations, is neglected. For this reason, the conductance of an air space is usually given for "$\frac{3}{4}$ inch or more," and includes surface conductances.

Thermal insulating values, and conductivities and conductances of some of the more commonly used materials for refrigerated storage construction are given in table 2.

Minimum insulation requirements

Through experience, minimum insulating values for floors, walls, and ceilings have been set for refrigerated apple storages in climates such as New York State. For walls, a minimum of 4 inches of corkboard or *its equivalent in insulating value* has been recommended. Where loose-fill types

Table* 2. Thermal insulation and conductivity practical values for various materials

Material	Conductivity (k)†	Conductance (C)‡	Thermal insulation: Resistivity (1/k)§ (per inch of thickness)	Thermal insulation: Resistance (1/C)‖ (thickness listed)
Building materials				
Common woods (average) 1 inch thick	0.92	....	1.09	....
Common woods (average) ⅞ inch thick	....	1.05	....	0.95
Plywood, ⅜ inch thick	....	2.12	....	0.47
Stone masonry	12.50	....	0.08	....
Concrete (gravel aggregate)	12.50	....	0.08	....
Concrete (cinder aggregate)	4.90	....	0.22	....
Concrete (lightweight aggregate)	2.50	....	0.40	....
Concrete block, 8 inches thick	....	1.00	....	1.00
Concrete block, 12 inches thick	....	0.80	....	1.25
Cinder block, 8 inches thick	....	0.60	....	1.66
Cinder block, 12 inches thick	....	0.53	....	1.88
Plaster Board, Sheet Rock, Gypsum Board, ⅜ inch thick	....	3.73	....	0.27
Insulating materials				
Reflective				
Reflective sheets 5 thicknesses, spaced ¾ and ¾ inch between insulation and sheathing	....	0.077	....	13.02
Rigid				
Corkboard	0.30	....	3.33	....
Wood fibre board	0.312	....	3.21	....
Mineral wool board	0.321	....	3.12	....
Vegetable fibre board	0.346	....	2.85	....
Foamglass	0.40	....	2.50	....
Styrofoam	0.25	....	4.00	....
Blankets				
Mineral wool	0.27	....	3.70	....
Wood fibre (Insulite)	0.33	....	3.00	....
Cellulose fibre	0.27	....	3.70	....
Glass wool (Fibreglas)	0.27	....	3.70	....
Loose-fill				
Regranulated cork (3/16-inch particles)	0.31	....	3.22	....
Buckwheat hulls	0.36	....	2.78	....
Vermiculite	0.48	....	2.08	....
Shavings (ordinary dry)	0.41	....	2.44	....
Sawdust (ordinary dry)	0.41	....	2.44	....
Cinders (screened and fine material discarded)	1.25	....	0.80	....
Redwood bark	0.26	....	3.90	....
Miscellaneous				
Air space (vertical, ¾ inch or more, ordinary surfaces)	....	1.10	....	0.91
Surfaces (ordinary non-reflective wall) still air	....	1.65	....	0.61
15 mph wind velocity	....	6.00	....	0.17
Roofing materials				
Asphalt shingles	....	6.50	....	0.15
Built up roofing (⅜ inch)	....	3.53	....	0.28
Heavy roll roofing	....	6.50	....	0.15
Wood shingles	....	1.28	....	0.78

* These values are from various sources, such as United States Bureau of Standards and manufacturers specifications.

† *Conductivity* (k) is rate of heat transfer in B.t.u. per hour per degree difference in temperature (F.) per square foot of surface through 1 inch thickness of material.

‡ *Conductance* (C) is the rate of heat transfer in B.t.u. per hour per degree difference in temperature (F.) per square foot of surface through the thickness as manufactured and used.

§ *Resistivity* (1/k), the reciprocal of k, is the insulating value of 1 inch of the material.

‖ Resistance (1/C), the reciprocal of C, is the insulating value of the thickness of the material as manufactured and used.

of insulation are used, a minimum of 6 inches is recommended. Although some of the loose-fill types have the same insulating value as corkboard, a greater thickness is recommended because plaster protruding from the joints in masonry walls reduces the effective thickness, and it is also difficult to pack these types of insulation to optimum density.

The thickness of insulation in the ceiling should be 25 per cent greater than in the walls because roof and attic temperatures may run 30° F. higher than outdoor air temperatures in the summer and early fall. A well-ventilated loft may reduce this temperature difference to 10° F. A minimum of 5 inches of corkboard or from 7 to 8 inches of loose-fill type of insulation is recommended for the ceiling.

Many storages have been built with no floor insulation. Because the ground temperature remains nearly constant at from 50° to 55°F. throughout the year and the outdoor temperatures under the floor are not high, many growers feel that no insulation is needed. Experience has shown, however, that with an uninsulated floor as much as 30 per cent of the total heat leakage is through the floor. For floor insulation, a minimum of 4 inches of corkboard or its equivalent is recommended. Some growers believe that this can be reduced to 3 inches because of the uniform ground temperature. There is, however, a difference of from 18 to 23 degrees between this uniform ground temperature and the storage temperature, and this difference remains the same *throughout the entire storage period* even when the outdoor temperature is at minimum. Therefore, the floor requires as much insulation as the walls.

Vaporproofing

Water is a rapid conductor of heat. The insulating value of a materia is, therefore, substantially reduced if it becomes wet. Damp insulation also makes conditions favorable for the rapid decay of the wooden parts of buildings. The protection of insulation against moisture is as important as the insulation itself.

Water vapor in the air has a natural tendency to diffuse or spread out independent of air movement. The vapor passes through materials that air will not normally penetrate. This tendency of vapor to move about is dependent on vapor pressure. As the temperature increases, the vapor pressure normally increases.

Air at a given temperature has a fixed capacity for water vapor. The higher the temperature, the greater the capacity for moisture. When air contains its full capacity of water at a given temperature, it is said to be *saturated*. If a volume of air containing a fixed amount of water (not at saturation) is cooled, its capacity to hold moisture is reduced. If no water is added or taken away during the cooling process, the air reaches satura-

tion temperature; that is, air reaches a temperature at which its water-holding capacity is equal to the original amount of water in the air. If cooled still further, the air has more water than it can hold and the excess condenses, resulting in a wet condition in the insulation.

The combined effect of water-holding capacity of air and of vapor pressure may result in the accumulation of moisture by insulation. If an insulated wall with no vapor barrier is in contact with warm air on one side and cold air on the other, air and moisture move from the warm side to the cold side through the insulation. Some of the moisture moves into the wall because of greater vapor pressure on the warm side. More moisture moves in with air when the wall "breathes," because of changing temperatures. As air approaches the cold side, its temperature, as well as its water-holding capacity, is lowered. Consequently, a point is reached at which the air is above saturation and water condenses in the insulation.

A vapor barrier should always be placed on the warm side of insulation and the cold side allowed to "breathe." "Breathing" from the cold side tends to carry moisture vapor *away* from the insulation. Cold air moving into the insulation warms up as it approaches the warm side and its water-holding capacity is increased. Thus it will tend to take up moisture.

The warm side of the insulation in a refrigerated storage is the *outside*. This is true most of the time apples are in storage. During December, January, and February there are periods when the outside air may be colder than the storage atmosphere. With temperatures as low as that, however, the vapor pressure is so low that little moisture diffuses into the insulated wall; any that does will move out again when the outdoor temperature rises.

In general, the types of vapor barriers can be classed as sheets or coatings. Typical examples of sheets are metallic-surfaced reflective papers, metallic foils or sheets, plastic bonded to foil, and asphalt-impregnated and coated felts or papers. Examples of coatings are aluminum paint and asphalt (asphalt is applied hot or applied cold in an emulsified form).

In applying any vapor barrier, there are three important rules to keep in mind. First of all, a barrier material should be selected that has enough resistance to the flow of water vapor to do the job. Secondly, the barrier should be well sealed and continuous; that means that the wall barrier should be sealed to the ceiling barrier and to the floor barrier. The question has often arisen as to the need of a vapor barrier over the ceiling insulation in a well-ventilated attic space. Experience of the authors over the past few years has shown that no one has been able to determine what constitutes a well-ventilated attic space. There have been instances where the ceiling barrier has been omitted and considerable trouble has

arisen with moisture in the ceiling. Consequently, the recommendation is to install the ceiling vapor barrier regardless; it is cheap insurance. The third important consideration is to use extreme care not to puncture the barrier when applying other materials, such as sheathing or siding.

In selecting the vapor barrier material, it is common practice to use the sheet type with wood-frame construction and the coatings with masonry construction. It is also possible to use the sheets with masonry, but not the coatings with wood. Coatings should not be used with cinder block unless the walls are first plastered.

Of the sheet-type barriers, most any of the metallic-surfaced reflective papers or metallic sheets and foils offer excellent resistance to the flow of water vapor. In asphaltic sheets, it is the amount of asphalt contained that determines the resistance to vapor. Those sheets that are both asphalt impregnated *and coated* in general have a higher vapor resistance than those which are merely impregnated. Examples of asphaltic sheets which can be used in refrigerated-storage construction are smooth-surface roll roofing (either 45-pound or 55-pound) and double-layer kraft paper with asphalt between (30–50–30 grade). In applying these sheets to wood-frame construction, the joints are made at the studs or at some other solid members and are well nailed. The first sheet is laid and nailed to the stud. Asphalt mastic is applied over the area where the lap will occur and the next sheet is applied and nailed to the stud. Finally, the lap joint and nail heads are covered with asphalt.

In applying coatings to masonry, a minimum of two coats of asphalt or metallic aluminum paint is recommended. The entire wall should be inspected after drying to insure that there are no skips or bare spots. The masonry surface itself should be smooth to insure a good seal. Under ordinary conditions, concrete blocks present a smooth enough surface so that the coating can be applied without further treatment if the mortar joints are carefully made. If cinder blocks are used, the surface of the wall will have to be plastered before applying the vapor-barrier coating.

Controlled-atmosphere storages present a special problem in vapor barriers. The gas-tight seal on the inside is an excellent barrier, but on the wrong side of the insulation. This has the effect of holding in the wall any moisture that does tend to accumulate in the wall, rather than to let it "breathe out" to the cold side of the storage wall. A recent inspection of walls of several controlled-atmosphere storages in the Hudson Valley by the authors revealed the seriousness of this problem. In every storage, even though vapor barriers had been installed according to standard recommendations for refrigerated storages, there were moisture accumulations in the walls. The solution of this problem is to apply a vapor barrier with as high or higher vapor resistance than the gas seal

on the inside. If sheet barriers are used, they should be either of metallic sheet or foil or of smooth-surface roll roofing of at least 65 pound weight. If coatings are used, a minimum of four coats should be applied.

Although the extreme care that is necessary in applying a vapor barrier seems a needless expense at the time, it should be remembered that it is only a relatively small portion of the overall cost of the storage. Moreover, in view of the job it will do and of its importance, the cost of the barrier is relatively negligible.

Additional details on sealing barriers and how to apply them so they will not be punctured are discussed in the sections on wall, ceiling, and floor construction.

Wall construction

The two common methods of wall construction used in this region are wood frame and masonry block. In masonry-block construction, concrete block are preferred to cinder block because, even though they are heavier to handle and lay, they are less porous and have fewer problems with moisture absorption.

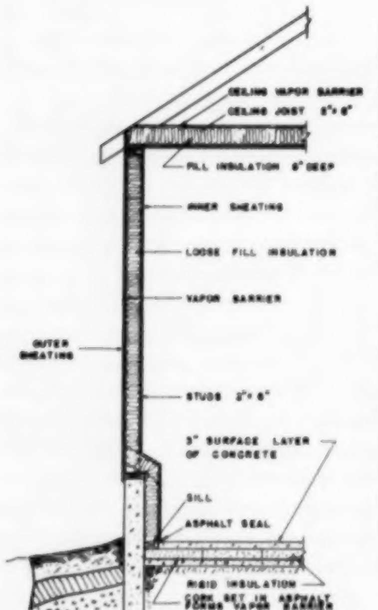


Figure 4. Details of wood-frame construction for refrigerated storage

Regardless of the type of wall construction, the first step is to install a good foundation and an adequate footing. Good drainage around the foundation and footing is essential to its long life and satisfactory performance. Details of foundation and footing construction are given in Cornell Extension Bulletin 741, *Roofs and Foundations*.

In wood-frame construction, the studs can be used to support the superstructure and hold the insulation (figure 4). With single-story construction and hand stacking, studs of 2-by-6-inch material are adequate for strength. Two-story storages and storages for fork-lift handling that have high walls require larger studs.

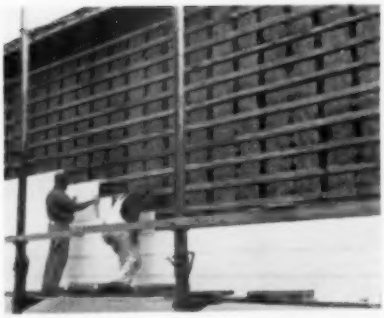


Figure 5. Applying siding on nailing strips to prevent puncturing the vapor barrier

The logical place to install the vapor barrier in wood-frame walls is on the outside of the studs. The sheets can be lapped, nailed, and sealed at the studs. This presents the problem of how to apply the outside sheathing or siding without puncturing the vapor barrier with nails. One method of solving the problem for horizontal wood siding is to apply vertically over the studs wooden nailing strips of adequate thickness to prevent the nails that hold the siding from penetrating beyond these strips. When fastening the nailing strips to the studs, mastic asphalt can be applied over the joint in the vapor barrier wherever there will be a nail to hold the nailing strip. If this is a thick layer of asphalt, the asphalt will squeeze around the nail and seal the nail when the nailing strip is applied. The same procedure could be followed in nailing the horizontal wood siding directly to the studs without nailing strips, but this would require more nails and much more time to apply the siding. For other types of siding, such as cement asbestos shingles, which require horizontal nailing strips, these strips can be applied to the studs and the nails sealed in the same way as described (figure 5).

Another way to apply vapor barriers to wood-frame walls is particularly adaptable to old buildings that are to be converted to refrigerated storage. Rather than remove the old siding and sheathing to apply the barrier from the outside, the barrier can be applied from the inside. It is applied directly against the inside of the outside sheathing and siding, but then it is rolled out over the studs and the joints made on the inside faces of the studs (figure 6). Inner sheathing can then be applied in such a way as not to puncture the barrier.

A typical storage of wood-frame construction is shown in figure 7.

In masonry construction, the supporting walls can be constructed of concrete block and the studding and sheathing can be

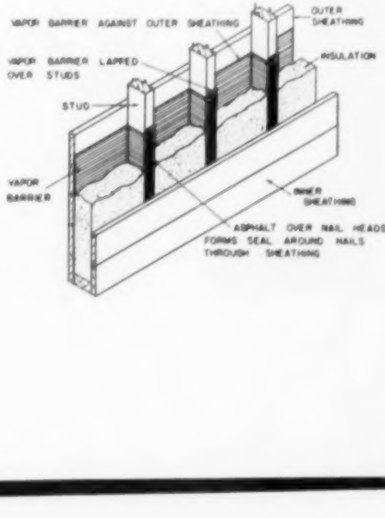
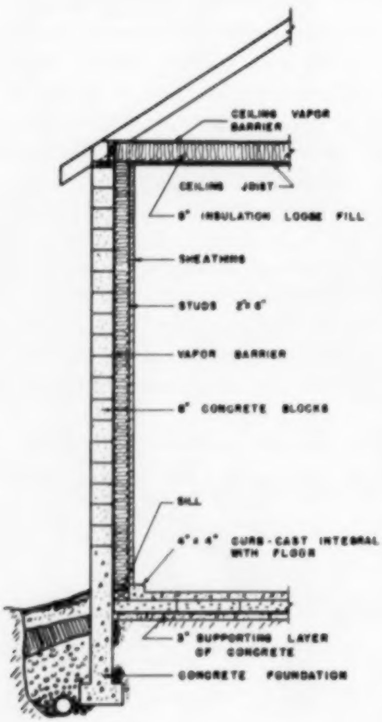


Figure 6. Applying a vapor barrier to a wood-frame wall from the inside

Figure 7. A wood-frame refrigerated apple storage in the Hudson Valley



built on the inside to hold loose-fill insulation (figure 8). If a rigid type of insulation is used with masonry block, some of the interior framing can be reduced. Cork-board, as an example of a rigid type of insulation that is manufactured in slabs, can be bonded directly to the wall. The slabs that form the first layer against the wall are first dipped in hot asphalt so that the four edges and the side that goes against the wall are covered (figure 9). When this is applied against the wall and the asphalt cools, a good bond is formed. The second layer is applied in a similar manner against the first with staggered joints (figure 10). Wooden pegs are driven in for additional support. It is desirable to install some type of

Figure 8. Details of masonry-block construction of refrigerated storages

Figure 9. Dipping a slab of corkboard into hot asphalt prior to placing it into a wall

Figure 10. Placing slabs of corkboard insulation against the wall

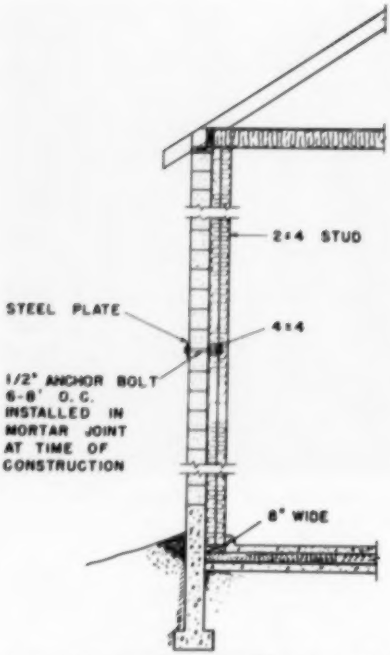


Figure 11. Intermediate support for studs in high masonry-block walls

interior sheathing merely as protection for the insulation against mechanical damage by crates, trucks, and the like.

When masonry block walls are used for storages with palletized handling, it may be desirable to install intermediate support for the studs that hold the loose-fill insulation because of wall height. One such method is shown in figure 11. When the block wall is built, a row of bolts spaced from 6 to 8 feet apart is installed in a mortar joint in the wall as shown. The vapor barrier is then applied in the usual way using care to seal well around the protruding bolts. A horizontal girt is then installed and fastened by the bolts without disturbing the vapor barrier. This girt furnishes the intermediate support for the studs.

There have been instances of masonry-block walls cracking. If the vapor barrier is an asphalt coating, such cracking would damage the barrier. The cracking can be prevented by careful construction. The first step is to install a foundation and footing that furnishes adequate support without settling.[1] Under ordinary conditions, 8-inch thick block walls should be adequate for single-story construction; 12-inch walls would be preferable for the first story in two-story construction to support the additional floor load on the second-story floor. Lateral bracing by means of cross walls, pilasters, or buttresses is important to the stability of masonry walls. For 8-inch walls, where the height exceeds 12 feet, lateral support should be provided at intervals of not more than 12 along the wall. If 12-inch walls exceed 18 feet in height, lateral support should be provided at intervals of not more than 18 feet along the wall.

It is becoming common practice to install vertical control or expansion joints in masonry walls to allow for expansion and contraction due to changes in temperature. Such joints are recommended at distances of 20

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[1] Refer to Cornell Extension Bulletin 741, *Roofs and Foundations*, by A. M. Goodman.

Figure 12. A large masonry-block refrigerated apple storage in the Hudson Valley

Figure 13. A 10,000-bushel masonry-block storage nearing completion

to 30 feet along the wall. Some means must be provided for the vapor barrier to follow these changes at the control joints. If asphalt is painted on the wall as a vapor barrier, it may be desirable to cover the joint with a strip of asphalt roll roofing with edges sealed to the regular barrier. This strip can be applied in such a way to give enough to permit expansion and contraction without damage to the barrier.

Two well-constructed masonry-block storages are shown in figures 12 and 13. The larger storage in figure 12 has operated successfully for several years. The smaller storage in figure 13 was completed in time for the 1954–55 storage season.

Floor construction

Many growers believe concrete-floor construction is costly. When, however, the advantages of a good solid-concrete floor on which to move both the equipment and the product itself, as well as to hold and protect the insulation, are considered, the concrete floor seems well worth the expenditure.

One way to insulate the floor is shown in figures 4 and 8. A 3-inch supporting layer is laid on solid, well-drained ground. Four-inch corkboard is laid in hot asphalt and then a 3-inch surface layer of concrete is laid on top. Some growers have used concrete on top of cinders. If this is done, a 4-inch layer of concrete is recommended on top of an 18-inch layer of screened cinders (with fine material discarded).

The floor insulation and the wall insulation are separated only by the wood sill. It is advisable to have such contact, because a great deal of heat leaks through the edge of the floor slab if it is not insulated from the outside wall. A hole 1-inch in diameter bored through the sill between each pair of studs gives ventilation to the floor insulation and allows it to "breathe."

The curb along the outside edges of the floor in the masonry construction serves a dual purpose: (1) It helps to prevent water from leaking down into the bottom of the insulation. (2) The stacks will never be closer to the wall than 4 to 6 inches, which means that there will always be some air distribution. In the frame construction, the curb holding the insulation inside the foundation prevents stacking against the wall. An asphalt seal around the edge of the floor between the concrete and the sheathing helps to protect the insulation from water on the floor.

It is important that the wall-vapor barrier be brought down and sealed to the floor vapor barrier to form a continuous barrier.

If fork-lift trucks or any other heavy loads of a similar nature are to be used on the floor, welded-wire fabric (mesh) reinforcing should be used in the concrete.

Ceiling and roof construction[2]

In figures 4 and 8, the ceiling joists and sheathing attached to the underside hold the loose-fill insulation. The depth of the ceiling joists is the same as the depth of insulation. Thus the tops of the joists come just to the top of the insulation, permitting the joints in the ceiling vapor barrier to be made on solid material. The ceiling insulation is continuous with the wall insulation, and an opening is left at the top of the wall to allow for the addition of more insulation if the wall insulation settles.

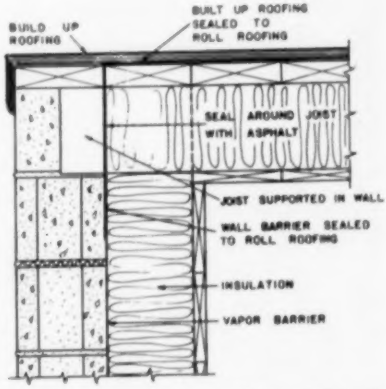

Figure 14. Sealing a built-up roof to the wall vapor barrier

The use of flat roofs is becoming rather popular in refrigerated apple-storage construction. These roofs are pitched at the rate of from $\frac{1}{8}$ to $\frac{1}{2}$ inch rise per foot of run, and are covered with a built-up roofing. When a five-ply built-up roof, with alternate layers of roofer's felt and melted asphalt, is used, the roofing may also serve as the ceiling vapor barrier. It is important that this barrier be extended over the edges of the roof and sealed to the wall vapor barrier. (figure 14).

Post-free interiors can be obtained under flat-roof construction by the use of steel "I" beams or trussed girders (figure 15) as the main support. In masonry construction, the girders can be supported in the wall by omitting a block or using half-blocks. After the girder is installed, plaster can be used to fill the wall opening around the girder, leaving a smooth continuous surface on which to apply the vapor barrier (figures 16 and 17). By supporting the girder one block higher in one wall than the other, enough slope is obtained for flat-roof construction with built-up roofing. The cores of the block directly under the girders should be filled with concrete. A small piece of metal lath in the joint under this block will hold the concrete until it sets.

Ceiling joists can be supported on top of the girders (figure 18), or on a ledger plate on the bottom flange of the girder to save headroom. If loose-fill insulation is installed between the joists, sheathing is necessary

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[2] Detailed information on the roof construction shown in figures 4 and 8 is given in Cornell Extension Bulletin 741, *Roofs and Foundations*, by A. M. Goodman.

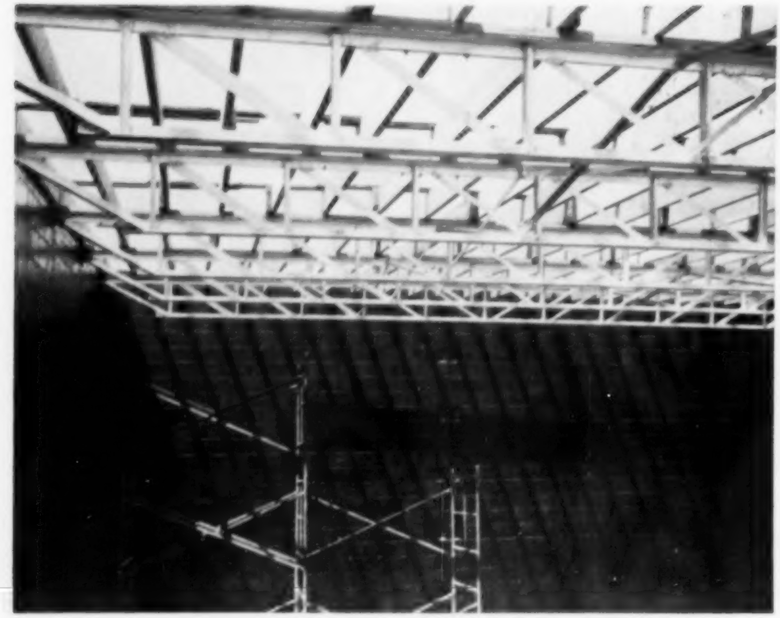


Figure 15. Trussed girders forming the main roof support for post-free construction

under the joists to support the insulation and a roof deck on top of the joists to support the roofing. With this type of construction, insulation is needed on the bottom of the steel girder to reduce the heat leak. Another method of flat-roof construction makes use of rigid insulation. The joists are installed as above and a solid deck is laid on top of the joists. Rigid insulation of the necessary thickness is laid on the deck, and the built-up roofing is applied directly to the insulation. If corkboard is used, asphalt will bond the insulation to the deck, and the asphalt built-up roofing will bond directly to the corkboard.

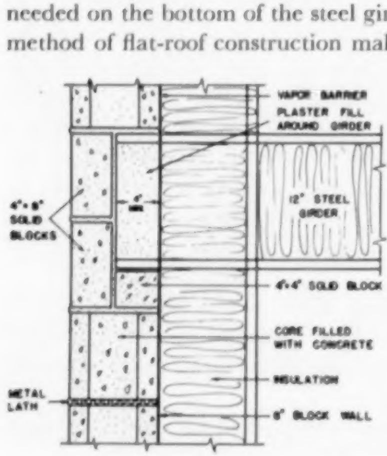
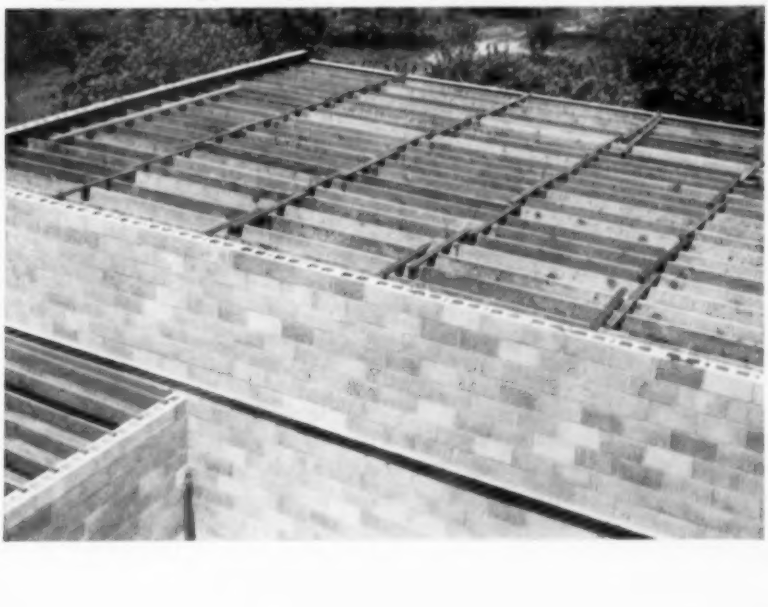


Figure 16. Supporting a girder in masonry-wall construction

Figure 17. Ends of ceiling joists supported in a masonry-block wall

Figure 18. Ceiling joists supported on top of girders in flat-roof construction



Other materials may require special bonding, since hot asphalt cannot be applied to all materials.

Doors

An entrance door is essential, but doors should be kept to a minimum because of heat leakage. In a storage where apples are hand stacked, one door 4 by $6\frac{1}{2}$ feet should be adequate. Where palletizing is practiced, the dimensions of the door are governed by the clearance necessary for the fork lift truck.

Because of the difficulty of construction, prefabricated refrigerator doors are probably the most economical to install. These are available in a wide variety of sizes. The edges of these doors are beveled and equipped with rubber gaskets to reduce heat leakage.

If apples are hand stacked, small loading ports, just large enough to admit one crate, at convenient locations at floor level, save refrigeration. A canvas flap hung over these ports further reduces heat leakage during the loading process.

Loading platform and grading room

Space must be provided for the handling of apples during the loading and unloading process. Space must also be provided for the grader and for the grading operation. The location of the loading platform and the grading room is important to efficient operation of the storage. The loading platform should be located for easy access by vehicles that bring apples from the orchard and by trucks that take apples to market. The arrangement of the loading platform should permit efficient straight-line flow of apples to or from the storage room.

The arrangement of the grading room depends somewhat on whether apples are graded into storage or graded out of storage. Whichever, the grader should be located for the most efficient flow of apples, either to or from the storage room. For fork-lift handling, enough space should be provided around the grader for maneuvering the fork truck.

Other space requirements that might be considered are storage for empty crates or shooks, stacking space around the grader for empty crates or filled crates, office space, retail room, lavatories, and the like.

Ratproofing

Loose-fill insulation seems to be attractive to rats as a nesting place. Buckwheat hulls, because of their grain odor, are particularly attractive. In wood-frame construction, there must be some way to exclude rats.

In sawdust and shavings, hydrated lime at the rate of 1 cupful of lime

mixed with each bushel of insulation has been used as a rat repellent. Aluminum sulfate has also been used to a limited extent.

One simple way to exclude rats is to place sheet metal around the outside, starting at the bottom of the wood sheathing and extending it 2 feet high. This prevents the rats from gnawing through, and is high enough so they cannot climb to where they can gnaw.

Refrigeration

Calculating the refrigeration load

THE refrigerating equipment absorbs and dispenses the heat that enters the storage and thus maintains proper temperature. The refrigeration load is commonly referred to in *tons of refrigeration*. This term is a hold-over from the days when ice was used. A ton of refrigeration is the amount of heat absorbed by a ton of ice melting at 32° F. in 24 hours. It requires 144 British thermal units (B.t.u.) of heat to melt 1 pound of ice at 32° F.; or 288,000 B.t.u. to melt 1 ton of ice at 32° F. Since a ton of refrigeration specifies that the ton of ice must be melted in 24 hours, a ton of refrigeration absorbs 288,000 B.t.u. in 24 hours. This is equivalent to 12,000 B.t.u. per hour or 200 B.t.u. per minute.

Heat is brought into the storage through several sources. First there is the heat leak through the walls, floor, and ceiling. Regardless of how well insulated, there is no perfect insulator, so this must be considered.

A second source of heat and one of considerable magnitude is the "stored" heat in the apples. Apples are brought into the storage at or near outdoor air temperature. To cool them to storage-room temperature, heat must be removed. The amount of refrigeration necessary to remove this heat depends upon the temperature range through which the fruit is cooled, the number of apples brought into the storage in a given length of time, and the rate at which it is desired to cool the fruit.

A third source of heat is through the process of respiration of the apples. At loading time, the apples are respiring at the most rapid rate. Respiration is reduced but is still present after the apples are cooled to storage temperature.

The fourth source of heat is called the *service load*. This is a general term that includes heat given off by the lights in the storage, heat from motors and equipment, heat given off by humans, and heat leakage when the doors are opened.

Any refrigeration system must be designed to meet the most severe conditions. Unfortunately, the maximum heat enters the storage from all sources at loading time. Heat leakage is at a maximum at loading time because outdoor temperatures are higher than at any other time through-

out the storage period. Field heat from the apples exists only at loading time. The process of respiration is most rapid when the apples are first loaded because of the high temperature of the apples. The service load is at its greatest because doors are being opened, workmen are in the storage more than at any other time, and lights are on for the workmen, and the equipment is in operation. Nevertheless, the storage temperature must be maintained even under these conditions, so refrigeration must be provided.

To calculate the refrigeration load, assume that a grower in the Hudson Valley near Hudson wants to build a storage for 10,000 bushels of apples. Walls are to be of 8-inch concrete blocks with 6 inches of regranulated cork and sheathed with finished lumber. The floor construction is to have a 3-inch layer of concrete as the base, with 4 inches of corkboard on top of this, and a surface layer of 3 inches of concrete. The ceiling is to be 8 inches of regranulated cork supported by sheathing of finished lumber, and the building is to be 40 by 45 feet with 14-foot ceilings. Apples are to be loaded during September at the rate of 1000 bushels a day. The storage temperature is to be held at 32° F.

Heat leak during loading

The materials of construction have different resistances to heat flow. The *overall* resistance of a wall, floor, or ceiling is equal to the *sum* of the resistances of the individual materials:

*Walls**	*Resistance*
8-inch concrete block	1.00
6-inch regranulated cork (3.22 per inch by 6 inches)	19.32
7/8-inch wood sheathing	0.95
Outside surface	0.17
Inside surface	0.61
Total thermal resistance of wall	22.05

* The vapor barrier has no insulating value.

$$\text{Total conductance} = \frac{1}{22.05} = 0.0453 \text{ B.t.u. per hour F.° sq. ft.}$$

The mean maximum September temperature at Hudson, New York, is 72.8° F., or approximately 73° F. This figure and the mean maximum September temperatures for other towns in the apple sections of New York State are shown in table 3.

The temperature difference between inside and outside is 73° F. − 32° F. or 41° F.

Table 3. **Mean maximum September temperatures in New York State***

Town	Temperature (F.)	Town	Temperature (F.)
Albany	72.6	Plattsburg	70.2
Buffalo	69.8	Poughkeepsie	75.5
Chatham	73.2	Rhinebeck	72.9
Fredonia	72.6	Rochester	71.8
Geneva	74.6	Sodus	72.3
Hudson	72.8	Syracuse	70.6
LeRoy	71.7	Walden	75.4
Lockport	71.5	Wappingers Falls	74.6
Lyons	72.9	Westfield	71.9
Penn Yan	74.2		

* From Cornell Bulletin 444, *The Climate of New York State*, by R. A. Mordoff.

Wall area = 14 × 40 + 14 × 40 + 14 × 45 + 14 × 45 = 2380 square feet.

Total heat leak through the walls = 0.0453 × 41 × 2380 = 4420 B.t.u. per hour.

Ceiling		*Resistance*
8-inch regranulated cork	8 × 3.22 =	25.76
$\frac{7}{8}$-inch wood		0.95
2 inside surfaces		1.22
Total resistance of ceiling		27.93

$$\text{Total conductance} = \frac{1}{27.93} = 0.0359 \text{ B.t.u. per hr. F.}^\circ \text{ sq. ft.}$$

Area of ceiling = 40 × 45 = 1800 square feet.

Temperature difference (10° more than through walls) = 51°.

Heat leak through ceiling = 1800 × 0.0359 × 51 = 3296 B.t.u. per hour.

Floor		*Resistance*
3 inches of concrete	= 3 × 0.08 =	0.24
4 inches of corkboard	= 4 × 3.33 =	13.32
3 inches of concrete		0.24
Inside surface		0.61
Total resistance of floor =		14.41

$$\text{Total conductance} = \frac{1}{14.41} = 0.0694$$

Area of floor = 40 × 45 = 1800 square feet.

Assuming an average soil temperature of 55° F.,
temperature difference = 55° F. − 32° F. = 23° F.
Heat leak through floor = 1800 × 0.0694 × 23 = 2873 B.t.u. per hour.

Wall leak	4,420
Ceiling leak	3,296
Floor leak	2,873
Total heat leak =	10,589 B.t.u. per hour.

Field-heat removal

Apples placed in storage are near outdoor temperature. If the apples have been left in the sun, the temperature may be even higher than air. Assuming the apples are placed in the above storage at air temperature, they must be cooled through a range of from 73° F. to 32° F. or 41° F. It was previously pointed out that equipment is designed to do this in 24 hours. In the problem it was assumed that a total of 1000 bushels were to be loaded in one day. A pound of apples will give up 0.92 B.t.u. in cooling 1° F. A figure of 55 pounds a bushel is assumed for apples. This includes the weight of the container which also must be cooled.

It then requires 55 × 0.92 or 50.6 B.t.u. to cool a bushel of apples 1° F. To cool 1000 bushels from 73° to 32° F., or 41° F., 50.6 × 1000 × 41 or 2,074,600 B.t.u. are required. Since this is required in 24 hours, the hourly requirements are 86,442 B.t.u. per hour.

Heat of respiration of apples

It has previously been stated that the rate of respiration of apples depends upon the temperature. The approximate evolution of heat through respiration of apples at different temperatures is shown in table 4.

From these figures the authors have estimated values for the evolution of heat at different temperatures. They are given in table 5.

The first loading day 1000 bushels are brought in at 75° F. and evolve heat at the rate of 9000 B.t.u. per ton. At the start of the second loading day, it is assumed that the first 1000 bushels are at storage temperature of 32° F. and evolve heat at the rate of 700 B.t.u. per ton. A second 1000 bushels is loaded and the cycle is repeated. The peak heat of respiration is on the last day of storage when 9000 bushels have already been loaded and are evolving heat at the low rate and the last 1000 bushels are placed in the storage. Consequently, the design is based on the last storage day.

Assuming the apples weigh 45 pounds a bushel (the container is not included) 1000 bushels weigh:

$$\frac{1000 \times 45}{2000} \text{ or } 22.5 \text{ tons}$$

Heat of respiration of 9000 bushels =

$9 \times 22.5 \times 700 = 141{,}750$ B.t.u. in 24 hours.

Heat of respiration of 1000 bushels =

$$1 \times 22.5 \times \frac{(9000 + 700)}{2} = 109{,}125 \text{ B.t.u. in 24 hours.}$$

Total heat of respiration = 141,750 + 109,125 =

250,875 B.t.u. in 24 hours.

$$\frac{250875}{24} = 10{,}453 \text{ B.t.u. per hour.}$$

Table 4.* Evolution of heat by apples at various temperatures

Temperature (F.)	Heat per ton in 24 hours
Degrees	*B. t. u.*
30 to 32	220 to 660
38 to 40	880 to 1,540
45 to 47	1,760 to 2,860
50 to 52	2,640 to 4,620
55 to 57	3,520 to 5,720
60 to 62	4,400 to 7,260
65 to 67	4,840 to 9,020
70 to 72	5,280 to 10,780
75 to 77	5,700 to 12,540
80 to 82	6,160 to 14,300
85 to 87	6,600 to 16,060

* These figures were taken from USDA Circular 278, *The Commercial Storage of Fruits, Vegetables, and Florist's Stocks*, by D. R. Rose, R. C. Wright, and T. M. Whiteman.

***Table 5.* Estimated evolution of heat of apples at various temperatures**

Temperature (F.)	Heat per ton in 24 hours
Degrees	*B. t. u.*
32	700
35	1,000
40	1,500
45	2,200
50	3,500
55	4,600
60	5,800
65	6,900
70	8,000
75	9,000
80	10,000
85	11,000

Service load

So many different items are involved in determining the service load that an arbitrary figure of 10 per cent of all other heat loads is assumed.

Total Refrigeration Load

Heat leak =	10,589	B.t.u. per hour
Field heat =	86,442	B.t.u. per hour
Heat of respiration =	10,453	B.t.u. per hour
	107,484	
Service load (10 per cent)	10,748	
Total	118,227	B.t.u. per hour

$$\frac{118{,}222}{12{,}000} = 9.85 \text{ tons of refrigeration}$$

It is obvious that design procedure must be followed for each individual storage because of a wide variety of conditions. Some rule-of-thumb figures can, however, serve as a guide in checking calculations or making a rough estimate of the refrigeration load. These figures are averages of calculations of storages insulated according to *minimum* recommended standards, and apples loaded under average conditions at varying rates. The figures in table 6 are based on the refrigeration load for each 1000 bushels of storage capacity.

Equipment

The simple refrigeration cycle

THE basic principle upon which a compression refrigeration system operates is that latent heat is absorbed or given up at constant

***Table 6.* Refrigeration in tons per 1000-bushel storage capacity at loading**

Type of load	Rate of loading per day in percentage of total storage capacity		
	10 per cent	7 per cent	5 per cent
	Tons	*Tons*	*Tons*
Heat leak	0.13	0.13	0.13
Field heat	0.6	0.4	0.3
Heat of respiration	0.1	0.07	0.05
Service load (10 per cent)	0.08	0.06	0.05
Approximate total	1	¾	⅔

temperature when a substance changes its state, such as a liquid to a gas or a gas to a liquid. The system changes a liquid to a vapor at one stage, thus absorbing heat from the surroundings. At another stage, the vapor is changed back to a liquid, thus giving up heat which must be removed.

The principal parts of a simple vapor-compression refrigeration system are shown schematically in figure 19.

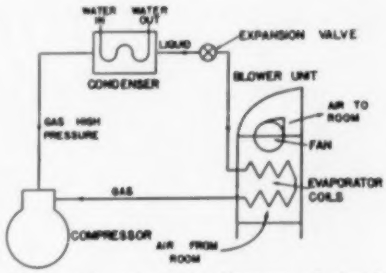


Figure 19. Schematic diagram of simple vapor-compression refrigeration system with blower

In this system, refrigerant liquid flowing through the line to the expansion valve is maintained under high pressure. At the expansion valve the pressure is reduced and the heat from the substance to be cooled furnishes the latent heat of vaporization to evaporate the refrigerant in the evaporator. This is the process that absorbs the heat. The compressor draws the vaporized refrigerant in and compresses it back to the high pressure. In the condenser, the vapor is cooled and, after its latent heat of evaporation is taken away, it is condensed into a liquid. It then flows to the expansion valve to repeat the cycle. Those parts of the system where the refrigerant is under high pressure, including the compressor and the condenser with their accessories, are often referred to as the *high-pressure* side of the system. Those parts that handle the low-pressure vapor, such as the expansion valve and the evaporator, are called the *low pressure side*.

Refrigerants

An ideal refrigerant: (1) should condense under moderate pressures and temperatures; (2) must evaporate at temperatures substantially lower than storage-room temperature and at pressures that can readily be produced; (3) must be non-corrosive to machinery, pipes, and equipment; (4) should not be toxic to humans or stored products; (5) should have an odor that is readily detected if leakage occurs; (6) should have a high latent heat of vaporization per unit of weight so a small amount of refrigerant circulated will give a desired refrigeration effect; (7) with its associated oil should present no fire or explosion hazard; (8) should be relatively inexpensive.

The two common refrigerants used in refrigerated apple storages are ammonia and freon-12.

Table 7. **Characteristics of compression systems**

Refrigerant	Guage pressure per square inch		Weight circulated per minute per ton	Power required per ton of refrigeration
	Evaporation, 5° F	Condensation, 86° F		
	Pounds	*Pounds*	*Pounds*	*Horsepower*
Ammonia	19.6	154.5	0.422	0.991
Freon	11.8	93.4	3.91	1.00

Ammonia is the oldest universally used refrigerant. It has been relatively cheap and is a comparatively efficient refrigerant. It cannot be used with copper or copper alloys, but requires iron or steel piping. If high enough concentrations of ammonia are present in the storage atmosphere, apples will be injured. Its disagreeable odor leads to ready detection of leaks. Operating costs per ton, both theoretical and practical, are lower for ammonia than for any other refrigerants used in industrial systems. Oil-saturated ammonia vapor in the right concentration in air will support its own combustion.

Freon-12 is rapidly replacing other refrigerants for use in apple storages. It is an odorless gas entirely harmless to humans and apples. It is non-corrosive and can be used with copper and brass. It is classed as non-combustible and non-flammable. Freon is more costly per pound than ammonia, and is more difficult to keep in a system. The use of copper piping with soldered joints can, however, reduce the cost of installation enough to help offset the greater cost of the refrigerant itself. Moreover, its safety from all aspects is an added point in its favor. Even though it may be more costly to replace a charge that might be lost, leakage into the storage will not damage the apples and there is no danger to operators working in or around the storage. A "halide" detector can be used to check for leaks.

The capacity and power requirements of a refrigerating system vary according to the conditions of pressure and temperature under which it operates. As a standard of comparison, the *standard cycle* is used when referring to vapor-compression refrigerating systems. The standard cycle is based on evaporation at 5° F. and condensation at 86° F. The comparison between ammonia and freon-12 based on the standard cycle is shown in table 7.

Compressors

Many different types and sizes of compressors are on the market (figures 20 and 21). The capacity rating of compressors is commonly referred

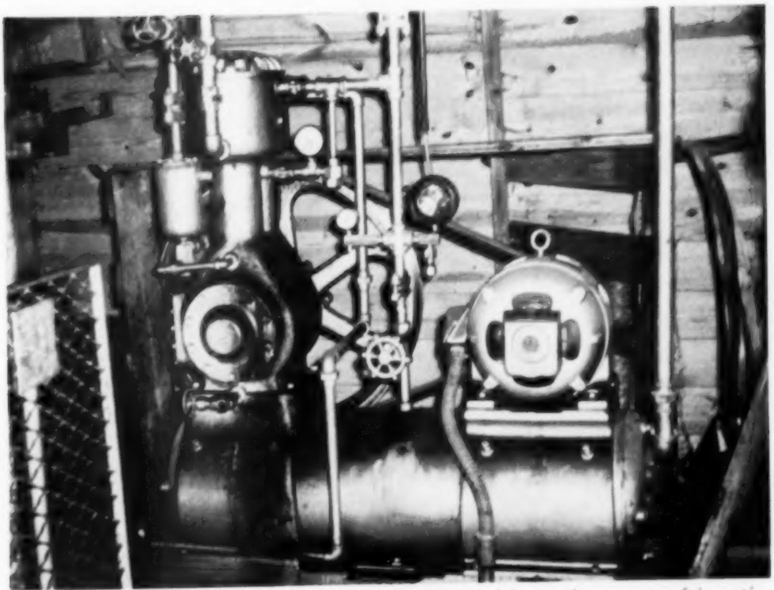


Figure 20. An ammonia compressor and condenser used for apple-storage refrigeration

Figure 21. A freon compressor used for apple-storage refrigeration

to in tons of refrigeration. The actual operating capacity, however, varies with the temperature of the refrigerant (and the pressure), the temperature of the room being cooled, the temperature of the medium surrounding the condensing coils, and the speed of the operation.

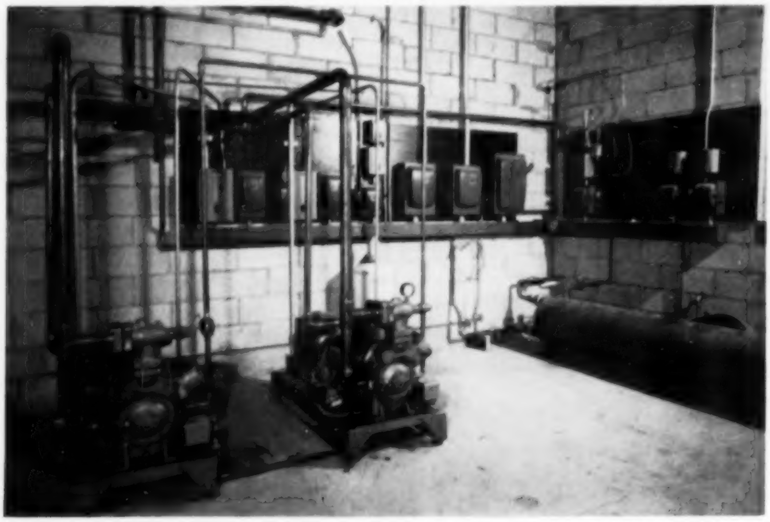
In general, compressor capacities increase with increases in suction pressure, so the compressor should be run with the suction pressure at as high a level as possible. Before increasing the suction pressure on any machine, the operator should check the capacity of the condenser; serious difficulty can arise if the condenser cannot handle the increased load.

Compressor capacities can be increased by increasing the speed of the machine. If the speed of the machine is doubled, the amount of refrigeration is doubled; but cost of power for operation of the machine is increased at a greater rate and the life of the equipment is shortened.

When the refrigeration requirement is specified, the manufacturer can furnish a compressor that will meet the requirement at a recommended suction pressure and at a recommended speed. Therefore, before any change in operation is made to increase the capacity of the machine, the manufacturer should be consulted.

It is more economical from the operation standpoint to install two compressors to take care of a given load rather than one of the same total capacity (figure 22). A combination of two compressors, one with two-thirds the total capacity and the other with one-third the total

Figure 22. Two compressors to carry the total refrigeration load



capacity is an excellent arrangement. At loading time, the total capacity of both compressors will probably be needed. After the fruit is cooled, but the heat leak is still high, the two-thirds-capacity compressor may be required for operation. After outdoor temperatures drop and the heat leak is low, the one-third capacity compressor with low operation cost may be enough to hold the temperature. Furthermore, with the two compressor system, the storage is not left completely without refrigeration if one of the compressors fails.

Many questions have been raised recently about the relative length of life of so-called "high-speed" compressors. In the first place, the term "high-speed" is not a true description. It is true that the number of revolutions per minute have been increased, but, at the same time, the length of stroke has been shortened so that the resulting speed of piston travel has remained the same. Consequently, there can be no more wear around the piston than formerly. Moreover, with the advancement in engineering design and the improvement in bearings, the increased revolutions per minute (rpm) should cause no concern. These units have the advantage of requiring considerably less space than other types.

Evaporators

The container into which the refrigerant evaporates and absorbs heat after leaving the expansion valve is called the *evaporator*. Formerly, many of the evaporators in refrigerated apple storages consisted of coils mounted on the ceiling or walls. Cold-air distribution depended upon the gravity movement of air. Consequently with this system, cooling was slow and temperatures were often uneven throughout the room.

By far the most universally used evaporator for apple storages today is the *blower* (also called *cooling unit* or *diffuser*) (figure 23). The blower or diffuser contains an evaporator coil enclosed in a cabinet with a fan that either blows or draws the air across the coils and forces it outward into the room (figure 19). Because of its positive action, this system gives better air distribution than the coil system and results in a more uniform temperature and more rapid cooling.

In a properly designed blower system, warm air is drawn from the storage and moved across the evaporator coils. The refrigerant is evaporating and absorbs heat from the air. This cool air is blown out into the storage and passed through the stacks where it picks up heat from the apples. It is again drawn into the cooler and the cycle is repeated.

The amount of air that should be circulated by blowers has been determined by experience. In general, the capacity of the blower should be equivalent to about one-third of the cubical content of the storage

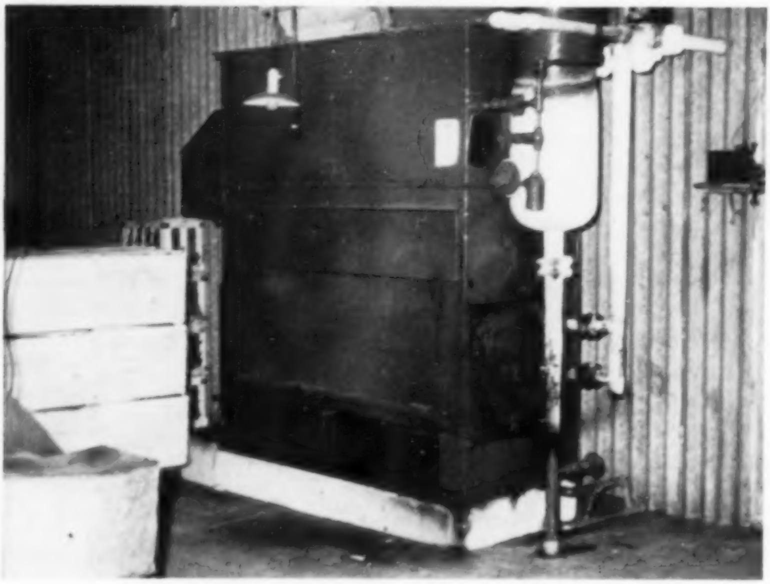


Figure 23. A blower for cooling in a refrigerated apple storage

room; or the c.f.m. should be equivalent to about 85 per cent of the number of bushels of storage capacity.

The amount of heat that a cooling unit absorbs depends upon the temperature difference (T.D.) between the refrigerant and the return air, the rate of heat transfer through the evaporator walls, and the area of cooling surface. The rate of heat transfer and the area of cooling surface are fixed in the design of the machine. Consequently, the rate of heat absorption for a given machine is dependent upon the temperature difference (T.D.). Manufacturers rate the capacity of cooling units in B.t.u. per hour per degree Fahrenheit of temperature difference. This basic rating times the temperature difference (T.D.) gives the operating capacity of the cooler.

When air passes across the cooling coils, it is not cooled to coil temperature. The reduction in temperature of air passing across the coils is commonly referred to as *range* or *split*.

It is best to keep the range as low as possible and still to maintain the desired amount of cooling. Excessive range leads to heavy frosting of the coils and a reduction of atmospheric humidity. As already mentioned a high relative humidity (90 per cent) is best in a storage.

If the return air from the storage room at this humidity is drawn into the cooling unit and cooled enough, the dew point is reached and there is condensation. Since the coils are cold surfaces, this is where most of the condensation takes place. If the coils are cold enough, condensation will be in the form of frost. A coating of frost reduces the rate of heat transfer because it acts as an insulator. The degrees that air temperature must drop for condensation from return air at 35° F. and for different relative humidities are shown in table 8.

Temperature range is greatest during loading because of the field heat of the load and of the opening of doors. The refrigerant temperature is run low to obtain rapid cooling. Consequently frosting is rapid. It is recommended that the temperature reduction should not exceed 10° F. This means that the temperature difference between the coils and the return air will be about 15° F. During the holding period, the range will then drop back to about 2° F. This low range emphasizes the importance of ample evaporator surface.

A number of methods are employed to defrost coils. One is called *off-cycle defrosting*. The refrigerant is shut off from the coils and the fan continues to run. Return air at above 32° F. melts the frost from the coils. Operation can be controlled either by hand or automatically. The chief disadvantage of this system is that the temperature of the storage rises during defrosting. The amount of temperature rise depends on the length of time required to defrost the equipment, which is relatively long. This system works well only in storages at 36° to 38° F. or above.

Another method used in large installations is the hot-gas method. The equipment is shut off and hot non-condensed gases are delivered direct from the compressor and circulated through the coils. This method is fast, but requires extra piping for the gases.

Table 8. **Temperature drop necessary for condensation from air at 35°F.**

Temperature drop (F.°)	Relative humidity
Degrees	*Per cent*
1.5	95
2.5	90
4.0	85
5.2	80
6.5	75
8.0	70
9.4	65
11.0	60
13.0	55
15.3	50

The water defrost method is becoming popular with many growers. In this method, water is sprayed onto the coils while the equipment is shut off until the frost is melted. This method is rapid, and the room does not have much time to warm up during the defrosting period. The process can be speeded up by the use of hot water from the condenser. Water defrosting lends itself either to manual or automatic control. The water from the spray and from the defrosting may be used to increase the humidity in the room by running the water with the fan on and the refrigeration off. If, however, the water defrost method is used, it is necessary to install a floor drain near the blower unit to drain away water that is not otherwise used. Water defrost is more popular than the two previous methods because it is normally cheaper to install than the hot gas defrost, and it is much more rapid than the off-cycle defrost.

Another method used to prevent the formation of frost on coils is the brine-spray system. A fine spray of brine, which has a lower freezing point than water, is continuously discharged down over the coils. The brine is accumulated in a sump and recirculated with a small pump. Moisture condenses in the brine and dilutes it. This is indicated by a rise in the level of the brine in the sump. When diluted, the brine can be recharged by the addition of salt in the form of sodium chloride. To maintain brine at 17° F. freezing point, requires a 12 per cent sodium chloride solution (12 pounds of sodium chloride per 100 pounds of solution). Salt is available in special 50-pound cakes which can be added directly to the brine in the sump. To maintain the correct amount of salt in the brine, the grower should watch the coils. As soon as frost starts to appear on the lower coils, it is an indication that the brine is becoming too dilute. This method of maintaining brine strength prevents the adding of too much salt.

One of the principal disadvantages of brine-spray units is the corrosiveness of the brine. Brine attacks steel and is particularly detrimental to aluminum. Considerable brine is thrown against the inside surfaces of the blower unit itself and, under certain conditions, is carried over through the duct work and discharged into the room. The life of the blower unit can be extended by periodic cleaning and washing down the inside surfaces and painting them with corrosion resistant material.

The corrosion of metal ducts and walls of the room by brine carried over in the air distribution system could be eliminated if the carry-over itself could be eliminated. Most manufacturers can supply eliminators to be installed in the blower unit. These eliminators take out a considerable amount of the brine spray if the blower is operated below a critical air-discharge quantity for that particular blower. Above this critical discharge, the effectiveness of the eliminator is considerably reduced. When

an eliminator is installed, the operator should check with the manufacturer and then make sure that the blower is operated at all times below critical discharge.

No eliminator is perfect, and almost invariably there is some carry over. Hence, if a brine spray unit is used, it is advisable not to use aluminum for duct work or wall lining. Even if galvanized steel is used, it is recommended that the interior of the duct be painted with corrosion-resistant paint.

Certain corrosion inhibitors that can be added to the brine to reduce its corrosiveness are available. Sodium dichromate, which is one of the inhibitors, cannot, however, be used in apple storages or any other storages for food. Phosphate inhibitors are under study at the present time and offer promise.

Another way to reduce carry-over that has been used in some areas is the installation of a plenum chamber. The blower discharges into this plenum and, due to the reduced velocity of the air, much of the water and accompanying salt is dropped out. The disadvantage to this system is that it becomes necessary to install the blower unit and the plenum outside the room to prevent taking up valuable storage space.

Condensers

The purpose of the condenser is to remove the heat from the compressed refrigerant gas so that it will condense. The heat absorbed by the condenser must be dispensed. Condensers are classed as air cooled, water cooled, or combination air and water cooled, depending upon the method of dispensing the heat absorbed from the refrigerant.

Air-cooled condensers are limited in use to small units. Since air is depended upon for cooling, the surrounding air temperature has a marked effect on the performance of the system. In the summer when air temperatures are high, the head pressure rises on the compressor and the refrigerating capacity is reduced.

Water-cooled condensers are used with all sizes of refrigerating systems. Two types of condensers are in common use: (1) the double-pipe and (2) the shell and tube. The double-pipe condenser consists of two pipes, one inside the other. Water flows through the inner pipe and refrigerant flows through the outer pipe around the outside of the water pipe. The shell-and-tube condenser consists of a series of tubes or pipes inside a shell much like a boiler. Water flows through the tubes and refrigerant through the shell.

The capacity of a condenser to absorb heat depends upon the surface area of the water pipe in contact with the refrigerant, the temperature of the water, and the rate of water supply.

The surface area is controlled in the design of the condenser. The required rate of water supply varies with conditions, but a rapid estimate may be considered from 70 to 120 gallons an hour per ton of refrigeration. With a good volume of cold water, it is possible to operate the compressor at low-head pressure, thus saving power and increasing the capacity of the compressor.

With an adequate water supply, the water is wasted after passing through the condenser; if the supply is limited, the water must be collected, cooled, and recirculated. Water may be collected and cooled in a spray pond or in a cooling tower. The spray pond has a water-collecting container above which nozzles spray water into the air to increase evaporation thereby resulting in cooling. The water can be cooled from about 5° to 10° F., depending on conditions surrounding the spray pond. In the cooling tower, mounted either on the roof or on the ground, water is sprayed from overhead and, in falling, air is passed through either by natural draft or by a fan. The air movement causes water to evaporate, resulting in cooling. The water can be cooled from about 7° to 15° F., depending on conditions surrounding the cooling tower. Because of the limited range of cooling of the water, large quantities of water must be pumped through the condenser when either a spray pond or cooling tower is used.

Another type of condenser which is becoming quite popular where the water supply is limited is the evaporative condenser (figure 24). These condensers consist of a cabinet in which are installed coils for carrying the hot refrigerant gases. Spray nozzles spray water down over the coils to cool the refrigerant. A fan blowing air up through the water and across the coils increases the amount of evaporation, which results in more cooling. In the winter, it is possible to shut off the water to these condensers and use for the cooling only the air blown by the fan.

Although the evaporative condenser represents an initial investment and some operating costs, only about 5 per cent as much

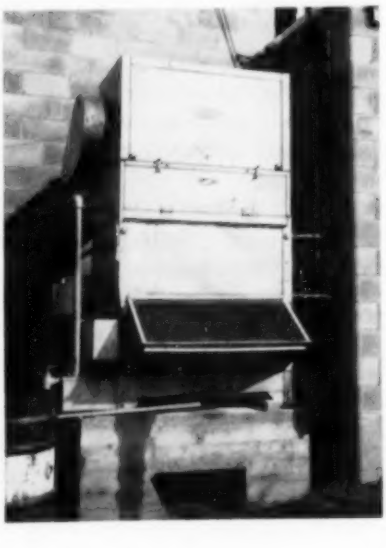


Figure 24. An evaporative condenser

water is used as with other condensers. If water is costly, the saving is considerable.

Combination air and water-cooled condensers are available for some units. These condensers operate as air-cooled units when conditions are right for adequate cooling by air. The flow of water is normally controlled through the head pressure on the compressor. When the air temperature is high and the head pressure rises to a pre-determined level, the water is allowed to flow to the condenser. Thus during colder weather, when the refrigeration load is light, there is normally little demand for water. The greatest demand for water is during loading and during warmer weather.

Controls for liquid

The expansion valve reduces the pressure of the compressed liquid refrigerant and allows it to evaporate. By opening or closing the expansion valve, the amount of refrigerant passing through the system can be controlled. Expansion valves are hand operated, automatic, or thermostatic.

The hand-expansion valve is a shut-off valve adjusted by the operator to feed just enough refrigerant into the evaporator to serve the purpose. If the load varies or if the operation of the compressor is intermittent to maintain the refrigerator's load, this type of valve requires constant changing and resetting. It is seldom used with automatic machines.

The automatic expansion valve consists of a needle valve attached to a diaphragm operating against a loading spring. A change in suction pressure operates against the diaphragm which opens or closes the needle valve. This changes the flow of the refrigerant and maintains a constant suction pressure. The suction pressure can be varied by an adjustment screw which changes the tension on the loading spring.

The thermostatic expansion valve differs from the automatic in that it maintains a constant temperature of the vapor as it leaves the evaporator. Consequently, the suction pressure is varied throughout the operation cycle so the superheat remains constant. The advantage of this type of expansion valve is a higher efficiency in the evaporator. During the entire running cycle, almost all the evaporator is fully active and effective.

Another type of liquid-control device used on a number of systems is the capillary tube. This is a small-diameter tube that restricts the flow of the liquid by friction and thus separates the high pressure from the low pressure as well as to meter the amount of flow. The capacity of the capillary tube is fixed in design by its diameter and length. During the off cycle, the pressures in the system equalize because the capillary tube is open at all times. Therefore it is necessary to employ a "balanced

charge" so no excess refrigerant will pass over the evaporator during off cycle and cause liquid "slugging." "Slugging" means that there is liquid refrigerant in lines that normally carry the vapor. The balanced charge merely means that the system is charged with only the refrigerant required by the refrigeration cycle.

Two other liquid controls have been used in some of the earlier refrigerating systems and are still in existence. These are the high-side float valve and the low-side float valve. The high-side float valve consists of a float chamber installed to take the liquid flowing from the condenser at all times. A ball float is connected to a needle valve that regulates the flow to the evaporator. When the liquid level rises in the chamber, the float opens the needle valve to the evaporator; as the liquid level falls, the flow to the evaporator is throttled down. The net result is an almost constant flow when the system is operating. When the compressor stops, some vapor still condenses in the condenser, so the float remains open for a short time. When this is passed, the flow stops because no more vapor is supplied to the condenser. The amount of liquid flowing after the compressor stops should be very small to prevent "slugging." For this reason a balanced charge is used with this system operated by a high-side float valve.

The low-side float valve also contains a float chamber and float-valve arrangement. The valve is so mounted that a drop in liquid level in the chamber *opens* the liquid inlet to maintain a constant level in the chamber. The valve is mounted on the low side of the system. The evaporator is flooded with liquid refrigerant. Heat absorbed from the storage room evaporates liquid in the evaporator. Thus evaporation lowers the liquid level in the evaporator and in the low-side float valve. The float then drops and allows more fluid to enter the chamber. The net result is an almost constant flow when the compressor is operating.

Temperature control

A thermostatic control switch is used almost universally to maintain the load temperature. A thermostat is placed in the storage room. When the temperature rises above the control point, the thermostat activates a switch that starts the equipment.

Since the refrigerating equipment is designed to remove heat that is flowing into the room at peak conditions, the temperature falls at any other but peak conditions. When it falls to the control point, the operation is interrupted. Thus, desired temperature is maintained by intermittent operation.

Since the thermostat operates on the temperature of air immediately surrounding the unit, care must be exercised to locate the unit properly.

If placed in a "warm" spot in the room, the equipment operates until that spot is cooled to the control point, so the rest of the room may be too cold. If the unit is placed in a spot that cools quickly, the unit may shut off before the rest of the room is properly cooled. Good air distribution alleviates much of this difficulty. The thermostat is commonly placed near the center of the room and in an aisle for easy access.

Another type of control similar to the thermostatic control is the pressure control. The pressure in the evaporator corresponds to the temperature in the evaporator. When the temperature in the evaporator rises, the pressure increases. During operation, the compressor reduces the pressure as well as the temperature. A pressure element is installed in the evaporator and connected to an electric switch, so a change in suction pressure causes intermittent operation of the equipment.

A solenoid stop valve is usually installed in the line ahead of the expansion valve. This valve opens when the equipment is operating and closes when it is off. This stop valve helps to eliminate evaporation of liquid after the equipment stops and helps to prevent liquid slugging of the line from the evaporator to the compressor.

Safety controls

Another extremely important control is the high-pressure cutout. This is merely a safety device. If something happens to interrupt the water supply to the compresser, the condenser gets hotter and hotter and the discharge pressure rises. It may get to a point where it is dangerous to the equipment. The high-pressure cutout is installed on the discharge side of the compressor. At a predetermined maximum safe operating pressure, the pressure control opens an electric switch that stops the compressor. The operating pressure of this switch can be adjusted.

Like any other safety device, *this switch must be in good operating condition at all times.* An annual check should be made of the switch. A simple way to check this is to start the compressor and then turn the setting of the high-pressure cut out down below the operating pressure of the compressor. If the switch cuts off, it is an indication that the switch is operating properly.

Numerous other types of controls for a variety of purposes are on the market.

Air Distribution in the Storage

It has been shown how to determine the amount of heat to be removed from a storage. Since the coils are confined to a small section of the room, the air in the immediate vicinity is cooled most rapidly. To cool the rest of the storage, this cool air must be distributed to other

parts of the room. There are other beneficial effects of air distribution, but the discussion in this bulletin is about temperature control only.

When air is cooled, it contracts and its density increases. This cool dense air tends to fall because it is heavier than the warm air surrounding it. The warm air being lighter, tends to rise. In a closed room, this sets up convection currents. A properly planned air distribution system for a refrigerated apple storage takes advantage of both the convection currents and the positive movement of air by the fans so that the two complement each other.

Blower units for air distribution are either floor mounted or ceiling mounted. The ceiling-mounted units are, however, used only in very small rooms. In the average-size apple storage, the floor mounted unit is most satisfactory. These units are designed to take air in at floor level and to discharge it horizontally at ceiling level.

Floor-mounted blower

When cold air is discharged horizontally at ceiling level, 40 feet is about the maximum practical distance that the air can be thrown with the velocities used in such application. In storage rooms that have neither dimension more than 40 feet, floor-mounted blower units give fairly satisfactory air distribution without ducts (figure 25). If either dimension exceeds 40 feet, ducts are essential. Even in smaller rooms better distribution can be obtained with ducts.

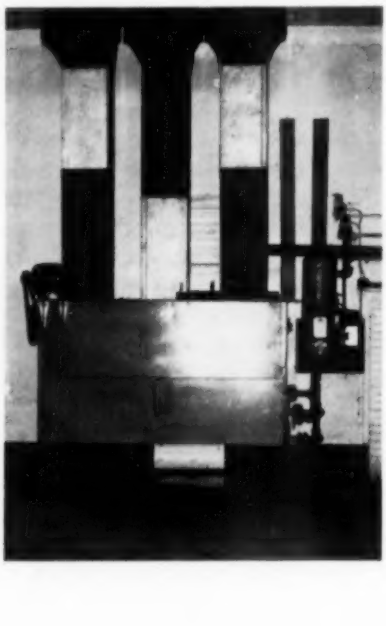


Figure 25. Blower installed in small room without ducts

Single duct

One of the simplest and most satisfactory methods of air distribution with a single duct, together with the proper system of stacking, is shown in figures 26 and 27.

The blower sets at one end of the room in the main aisle through the center of the room (figure 28). A vertical duct carries the air to the main duct. This main duct runs the length of the room over the main aisle. Slots are made in the side of the main duct so the air is blown horizontally over the

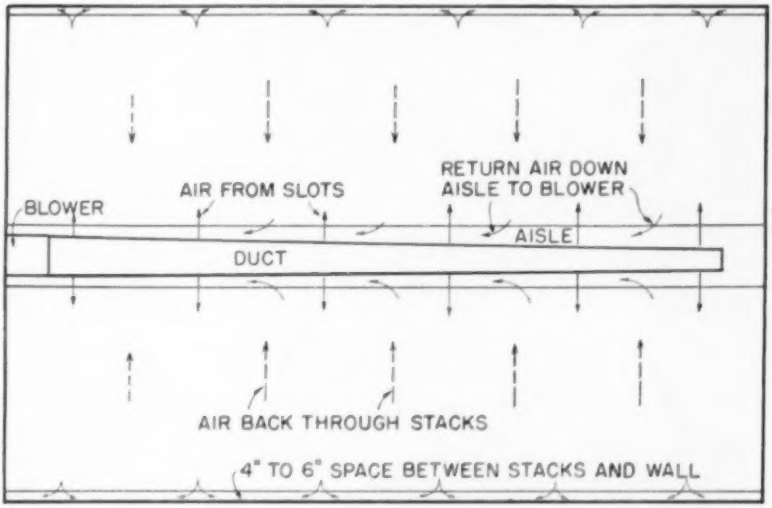
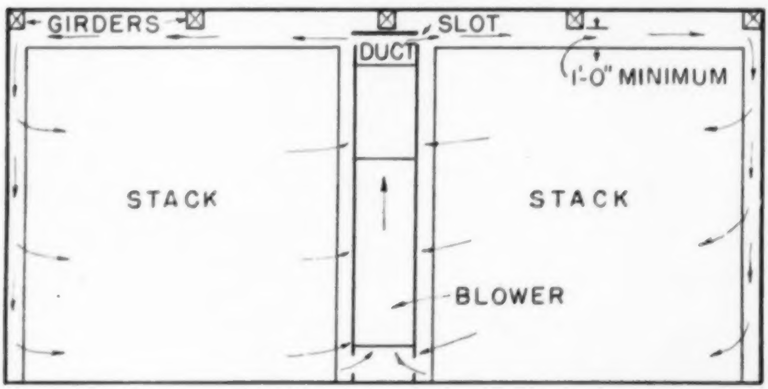


Figure 26. Plan of air distribution from a single duct

top of the stacks toward the side of the room. A minimum of 1 foot of head room between the top of the stacks and any obstruction, such as joists, is essential. If there are entrance doors at both ends of the room, the blower will have to be offset from one of the doors (figure 29). The

Figure 27. Cross section of air distribution from single duct



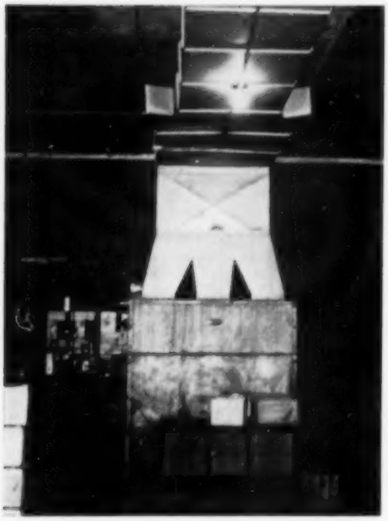
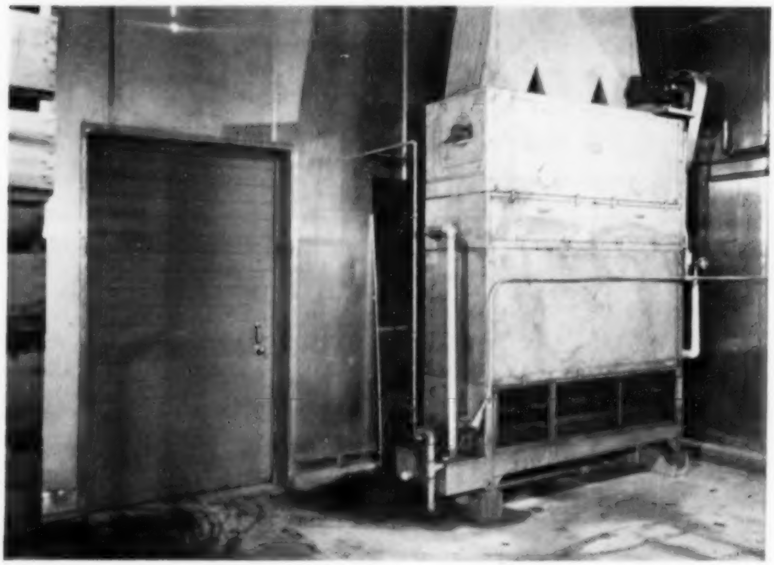


Figure 28. Blower unit with single duct in a refrigerated apple storage

first few feet of the horizontal duct is then curved gradually so the duct will run down the center of the room (figure 30).

At the side walls, a space of from 4 to 6 inches is left between the stacks and the walls. This space acts as a plenum chamber where pressure is built up which forces the air back through the stacks. The air from the stacks comes back into the main aisle which acts as a return duct for the air to the suction inlet of the blower. To facilitate air passage through the stacks, a space of 2 inches between the rows of crates is recommended. If the crates have lids, slats should be placed parallel to the direction of air flow to leave a space between

Figure 29. Blower unit offset from entrance door



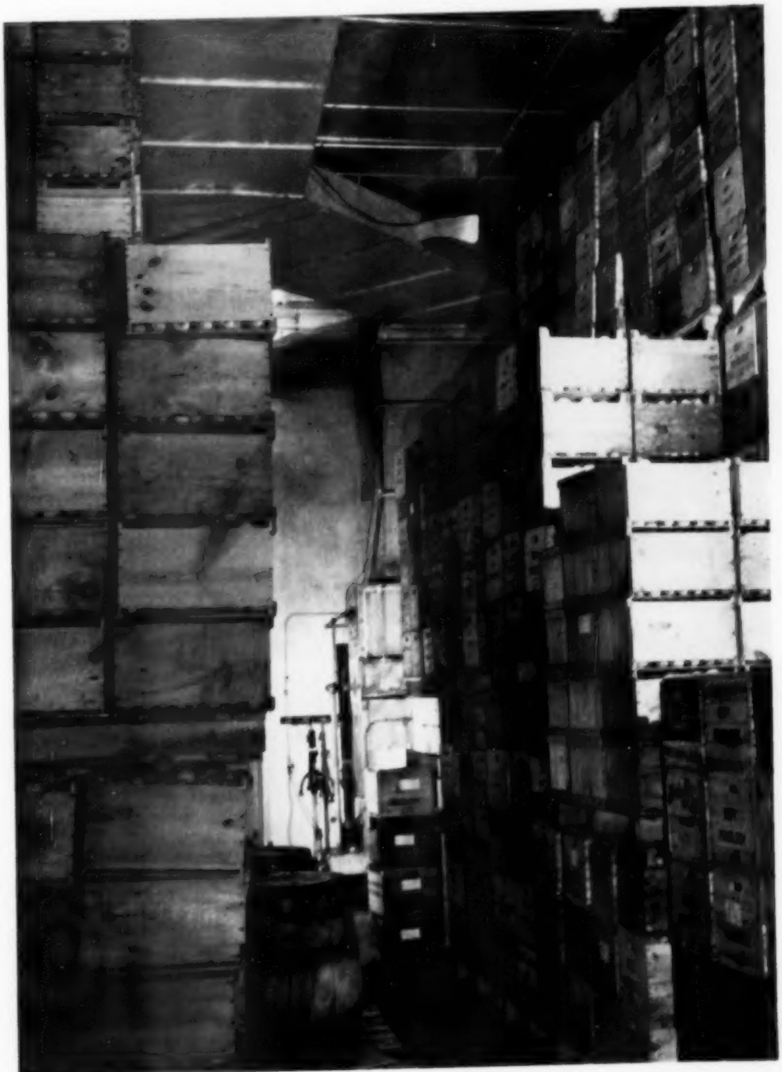


Figure 30. Curving the first few feet of duct from a blower offset from the entrance door

Figure 31. Running the duct along one side of narrow room

tiers. New England apple boxes are so constructed that the space is left in stacking, provided they are stacked right side up. When stacked on their sides, the spaces are vertical and do little good. A good rule to remember is that air passing through the stacks should brush at least one side and preferably two sides of *every* crate.

In stacking palletized crates, the direction of the sleepers under the pallets seems to make little difference on the rate of cooling, provided the spaces are left between the crates themselves. If, however, spaces are not left between the crates, the sleepers should run parallel to the normal direction of air flow through the stacks. This latter method of stacking is more convenient because it is common practice to turn the fork truck off the center aisle toward the wall.

In rooms that are not more than 30 to 40 feet wide, it may be desirable to run the duct down one side of the room (figure 31). Air is discharged from the slots in one side of the duct only. It is important with this system to leave an aisle approximately 2 feet wide along the wall under the duct for the movement of return air.

Two ducts

In wide rooms, where the width exceeds 60 feet, it may be desirable to consider the two-duct system shown in figures 32 and 33. The ducts

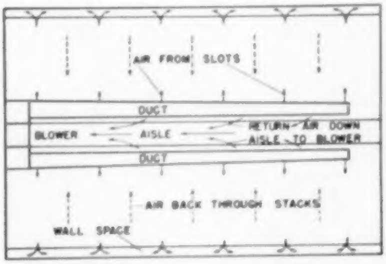


Figure 32. Plan of air distribution from a two-duct system

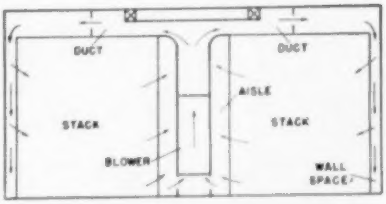


Figure 33. Cross section of air distribution from a two-duct system

are so spaced that the distance to the wall does not exceed the maximum for throw. Each of the ducts discharges from slots on one side only; the side toward the wall (figure 34). Other than the ducts, the system of air distribution is similar to the single-duct system. The two-duct system might also be used in rooms with large girders running parallel to the

Figure 34. Two ducts, each discharging air from one side only

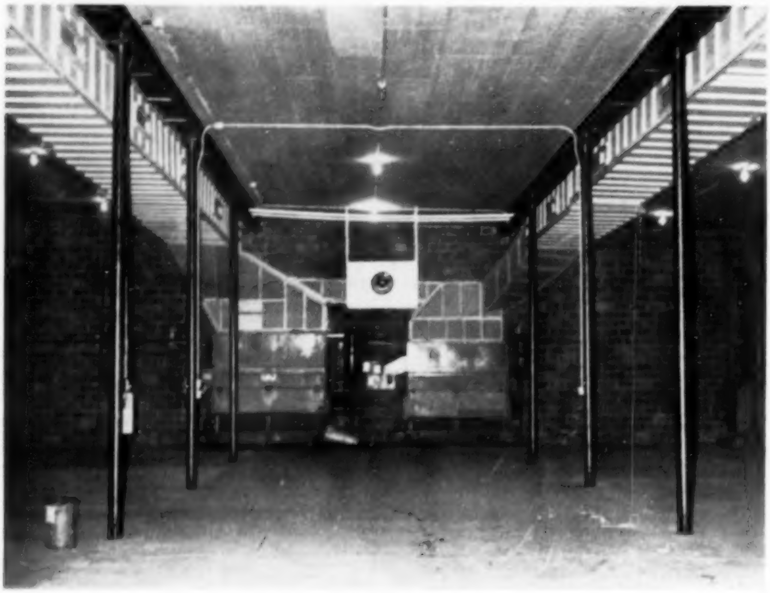


Figure 35. Two air ducts and two blowers in a large storage room

duct which would obstruct the air discharged from the duct. The two ducts can be placed just outside and adjacent to the girders.

A system of two ducts and two blowers installed in a large room is shown in figure 35.

Aisles

Aisles other than the main one affect the distribution of air. Where an aisle runs parallel to the duct, but to one side of it, the air moving across the top of the stacks drops into this aisle and short-circuits back through the center stacks without passing through the stacks beyond the aisle. This short circuiting may be prevented by bridging across the top of the aisle with canvas or light wood.

If an aisle runs perpendicular to the duct, air tends to channel down this aisle and to return without passing through the stacks. Hanging curtains across this aisle helps to prevent the channelling.

The space between the outer stacks and the wall should be blocked at the ends. Stacking crates at the end of the space during loading is enough. If the end is not blocked, the air tends to move out the end and around the stacks rather than through them.

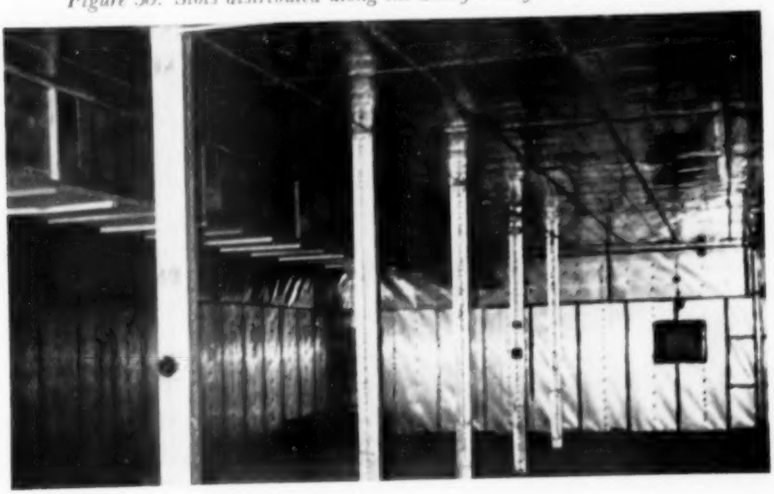
Air-duct design and construction

The area of cross section of the duct (square feet) times the velocity of air flowing through the duct (feet per minute) give the quantity of air flowing in cubic feet per minute.

The quantity of air to be distributed has already been established (page 40). It is recommended that the duct be designed for air velocities of 800 to 1200 feet per minute. Thus the quantity of air to be moved divided by the velocity gives the area of the duct in square feet. The dimensions of the cross section of the duct can be determined from this. When a rectangular duct is used, a duct of square cross section offers least resistance to air flow. Economies of construction sometimes make it desirable to make the cross section a rectangle. Then the longest dimension of the rectangle should be no greater than 3 times the shortest dimension.

Slots in the side of the duct distribute air to the sides of the room. The spacing of slots may vary according to conditions. Where the room is divided into bays by columns, one slot may be needed for each bay. A spacing of 15 to 20 feet along the duct is an average figure (figure 36). The size of the slot may be determined by the quantity of air discharged through each slot and by a desirable air velocity from the slot. An average air velocity of 800 feet per minute is often used. It is assumed that each slot discharges the same amount of air, so the portion each discharges can quickly be computed.

Figure 36. Slots distributed along the duct for uniform air discharge



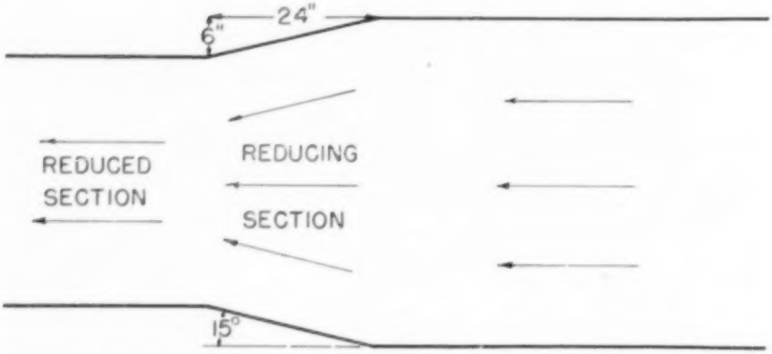


Figure 37. Reducing duct size

In designing the main duct, it must be realized that the amount of air flowing in the duct after the first slot is passed is reduced by the amount discharged from the slot. To maintain the same velocity throughout the duct, the size should be reduced after each slot. One way to reduce the area is to taper the ducts uniformly from one end to the other. Another way is to build a straight section to the first slot, reduce the area after the slot, and continue with a straight section of smaller size. Caution must be exercised in reducing the size, because too abrupt a change causes excessive turbulence and friction losses. When a reduction is made, the wall of the reducing section should make an angle with the wall of the straight section not exceeding 15 degrees. This means that the wall can be moved in 6 inches in a distance of 2 feet along the duct. This is shown diagrammatically in figure 37.

Of the two methods of duct construction, the continuously tapered duct is probably the simpler to construct and gives as good performance. It is common practice to keep the depth of the duct the same throughout its length and taper in the sides to give the necessary reduction in cross-sectional area, provided the ratio of one dimension to the other does not exceed the value of 3.

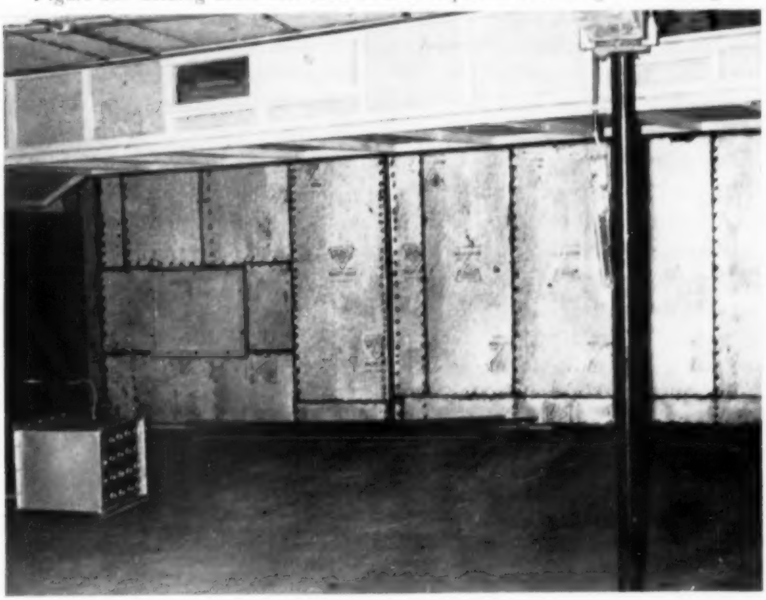
It is best for the air to come out of the side slots in the duct perpendicular to the main duct. Plain slots cut into the duct will not do this. Instead, the air comes out of the duct at an acute angle with the duct in the direction the air is flowing in the duct. Some growers have installed scoops inside the duct to improve the distribution pattern. In some experimental work conducted at the University of Wisconsin on the performance of side outlets in horizontal ducts,[3] curved deflectors

[3] *The Performance of Side Outlets in Horizontal Ducts*, by D. W. Nelson and G. E. Smedberg. Amer. Soc. Heating and Ventilating Eng. Trans., 49:58. 1943.

in the slot were used, thin vertical strips perpendicular to the face of the slot were placed in the slot, a single scoop was placed in the duct, and these were compared with a plain slot. The curved deflector gave the best distribution pattern and the vertical strips were nearly as good. The single scoop did not improve the flow pattern over the plain slot. From these results, it would seem that the vertical strips (sheet metal) would be the best to use in slots in air ducts for apple storages. Although not quite so effective as curved deflectors, they are much simpler to install. A spacing of 2 inches between strips would seem desirable.

Regardless of how carefully the duct has been designed, it is important to have the delivery of the slots checked as soon as the system is installed. The sales engineer for the company furnishing the refrigeration system should have the necessary test equipment to determine slot discharges. If any unevenness of discharge is found, the system should be balanced. Balancing may be possible by the use of sliding doors over the slots (figure 38). The first slots near the blower end of the duct sometimes do not discharge as much as is desired. To correct this, it may be necessary to install small scoops inside the duct to increase the discharge from these slots, or it may be necessary to damper down some of the slots near the other end of the duct.

Figure 38. Sliding doors over slots in duct to permit balancing the discharge



With so many materials of construction, it is impossible to recommend any one as best. If ducts are wood construction, the frame work can be placed on the outside with sheathing inside. This results in a smooth inside surface with least resistance to air flow. The authors have seen a number of installations of wood ducts framed on the outside and sheathed inside with a manufactured pressed board. These ducts are simple to construct and seem to work satisfactorily.

It is a fallacy to spend a lot of time and money in the design or construction of the duct and then pack apples in front of the slots. The air from the slots should have unobstructed passage all the way across the top of the stacks. The top of the slots should be below any obstructions, such as beams, joists, and the like.

Humidification

The amount of moisture in the storage atmosphere is normally quite high. There is condensation on the cooling coils, and this moisture is taken from the storage atmosphere. It has been found by experience that crates, even constructed of green lumber, absorb water when placed in high humidity atmosphere such as is desirable in the storage. Thus it is difficult to maintain humidity in the storage. Conditions are especially bad at loading time when doors are being opened and the outdoor air comes into the storage, when the cooler is operating on maximum temperature difference, and when fruit is being put into the storage.

One of the number of ways to increase humidity is to run the blower at as low temperature differential as possible to keep condensation at a minimum. Most growers keep the floor wet during loading, so water will evaporate from the floor. If the drip from defrosting coils runs on the floor, this water eventually gets back into the storage atmosphere. (This is undesirable if a brine spray is used.)

A number of companies manufacture nozzles that break up water into a very fine spray when operated on the water pressures commonly found in farm water systems. Such nozzles can be installed in the storage for increasing the humidity. There will be some drip from these nozzles; but, if they are installed over an aisle, no harm will be done. The water lines are air vented so that they will drain free and not freeze up.

During the holding period, it may be possible to hold the humidity by infrequently wetting the floor, especially if the temperature differential is held to minimum. There are well-constructed storages in the Northeast that have no humidity problem after the initial temperature-reduction period.

Precooling

It is possible to remove field heat rapidly from apples before they go

into storage. Precooling can be done most rapidly by flooding the apples with ice water. Rapid removal of field heat by precooling lessens the refrigeration load on the storage room. Less refrigeration equipment is, therefore, required in the storage space when apples are precooled. It should be remembered, however, that one is just moving the refrigeration job from one place to another. The required refrigeration capacity will actually be greater when precooling is practiced because of the speed involved. Hence, total costs will be somewhat higher.

Hydrocooling (water cooling) usually removes field heat and brings the temperature of apples from 70° to 33° to 34° F. in one hour. Removing field heat from apples in a well-designed apple storage usually requires from 72 to 96 hours. Actual study with Cortland apples has shown no advantage of the faster cooling after a four-month storage period. In a poorly designed apple storage, from three to four weeks may be required to remove field heat. Hydrocooled apples compared with very slowly cooled fruits had much better condition after four months of storage.

Common Troubles in Refrigeration Operation

MOST of the common troubles encountered in refrigeration operation can be eliminated by a periodic inspection during shut-down by a good maintenance man. When contemplating buying refrigeration equipment, the prospective purchaser should always consider the service facilities in his area for that make of equipment.

Some of the more common operation troubles, with possible causes and remedies are listed. Where the remedy is obvious, this has been omitted.

Short cycling (compressor on and off for short periods)

Possible cause	Remedy
1. Too large a compressor	1. Smaller pulley on motor
2. Thermostat differential too close	2. Widen differential
3. Discharge valve leaking	3.
4. Shortage of gas	4. Look for a leak, repair, recharge
5. Leaky expansion valve	5. Replace valve — use solenoid ahead of expansion valve
6. Too much refrigerant	6. Bleed
7. Cycling on high pressure cut-out	7. Check water supply to condenser

Unit operates too long

1. Shortage of refrigerant	1.
2. Air in system	2. Purge
3. Control contacts frozen	3. Clean points or replace control
4. Dirty condenser	4. Clean
5. Inefficient compressor	5. Service valves and pistons
6. Plugged expansion valve	6. Clean or replace
7. Heavily frosted coils	7. Defrost
8. Insufficient insulation in storage	
9. Unit of insufficient capacity	

Head pressure too high

1. Too much refrigerant	1. Bleed
2. Air in line	2. Purge
3. Dirty condenser	3. Clean
4. Not enough water supply to condenser	
5. Water shut off to condenser	

Noisy or pounding compressor

1. Low oil level	1. Add oil
2. Defective belts	2. Replace
3. Loose pulley or fly wheel	3. Tighten
4. Worn bearings	4. Service
5. Mountings worked loose	5.
6. Liquid slugging [4]	6. Adjust oil level or refrigerant charge

Suction-line frosts

1. Expansion valve open too much	1. Adjust expansion valve

[4] Other causes of slugging may be a leaky expansion valve or solenoid. It is difficult to get a solenoid tight after it has been used. If the condition persists, it may be necessary to install an accumulator or trap that collects the liquid and by-passes the compressor to the receiver. A large accumulation of liquid in the suction *line* may damage the compressor.

Hot liquid line

1. Shortage of refrigerant
2. Expansion valve open too much

Frosted liquid line

1. Receiver shut-off practically closed or plugged	1. Open valve or clean

Where ammonia has been used as a refrigerant, there have been a few explosions. Although these instances are rare, two such explosions occurred in the Hudson Valley in recent years. From the evidence collected on the causes of one of the explosions, several conditions seem to have contributed to the explosion:

Apparently, there was liquid refrigerant in the suction line which caused the compressor head to blow and to release the ammonia to the machinery room. Because there was not enough ventilation to clear the ammonia from the room, a combustible concentration built up and the mixture ignited and caused an explosion and considerable damage. The center of the explosion seemed to be at the switchboard, indicating that an automatic switch had arced and ignited the mixture.

From this experience, it is obvious that a pounding compressor should be shut off and checked. Adequate ventilation of the machinery room prevents the build-up of dangerous concentrations of ammonia if there are leaks. A master switch on the outside of the building permits all compressors to be shut off without personnel going into the danger area and where an arc will do no harm.

If trouble arises in the operation of any equipment, it is an investment in safety to cease operation until the trouble is located and remedied. If the trouble cannot be found, an experienced service man should be called.

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